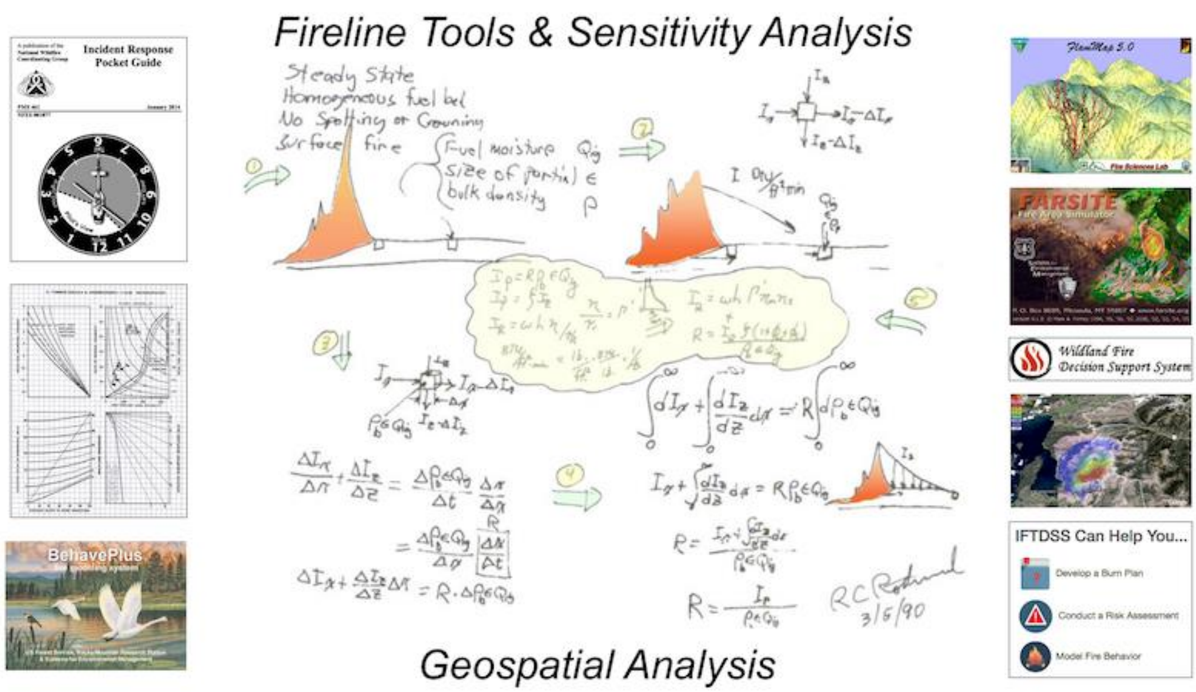
FIRE BEHAVIOR FIELD REFERENCE GUIDE

PMS 437 May 2017 (review draft)



National Wildfire Coordinating Group
Fire Behavior Subcommittee |
Boise, Idaho

This product is available electronically at: https://www.nwcg.gov/publications and on the web at http://www.fbfrg.org/.

Sponsored for National Wildfire Coordinating Group (NWCG) publication by its Fire Environment Committee (FENC). Prepared and maintained by the Fire Behavior Subcommittee (FBSC). Questions regarding the content of this product should be directed to the NWCG Fire Behavior Subcommittee, National Interagency Fire Center, 3833 S Development Ave, Boise ID 83705. Questions and comments may also be emailed to BLM_FA_NWCG_Products@blm.gov

Previous editions: 1992, 2001, 2014. 1992 edition was maintained and published through National Advanced Resources Technology Center (NARTC, currently known as the National Advanced Fire and Resource Institute (NAFRI)). 2001 and 2014 editions published by NWCG

Acknowledgements

Robert Ziel compiled the 2014 version of this guide and has been responsible for producing this latest 2017 edit as well.

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In addition, current and past members of the Fire Behavior Subcommittee were instrumental in the coordination and review of these reference materials. Those individuals include Don Boursier, Kyle Cannon, Tony Harwood, Dan Jimenez, John Kern, Jason Loomis, Risa Lange-Navarro, Sandra “Punky” Moore, Rick Mowery, Tami Parkinson, Larry Van Bussum, and John Saltenberger.

Preface

The Fire Behavior Field Reference Guide (FBFRG) was developed as a hands-on user tool for field going Fire Behavior Analysts (FBANs), Long Term Fire Analysts (LTANs), and other fire behavior operational personnel. The FBFRG was created by the S-590 steering committee. The guide was developed by course coordinators, coaches, and field going personnel as a reference tool and look up guide for use in training and in the field by fire behavior analysts and fire managers alike.

The FBFRG was first published in 1989 through the National Advanced Resources Technology Center (NARTC), currently known as National Advanced Fire and Resource Institute (NAFRI) in Arizona. It was discontinued after their last update in 1992. The reason for discontinuing the guide was primarily lack of funding to maintain, update, publish and distribute the product, which existed as a 6”x 8” bound reference.

In the years following the discontinuation of the published guide, the fire behavior user community petitioned the FBSC to update and re-establish the FBFRG. It was republished with the 1992 content as an NWCG product in 2001. In 2010, the FBSC consulted with a private group to officially analyze the needs of the field and document content needed for the reference guide.

Once the needs analysis was completed the Subcommittee awarded a contract to Robert (Zeke) Ziel, a qualified FBAN and LTAN, to conduct a substantial revision of the reference guide. It was republished in 2014.

Funding of this project, over time, have been provided by NWCG and the USDA Forest Service RMRS Wildland Fire Management Research Development and Application group located at the National Interagency Fire Center.

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Introduction

The Fire Behavior Field Reference Guide (FBFRG) is maintained as a hands-on user guide for field going Fire Behavior Analysts (FBANs) and Long Term Fire Analysts (LTANs) along with various operation personnel. It also serves fire behavior training as an important learning reference.

The guide contains helpful references to the factors from the fire triangle (fuels, weather, topography), including features that are vital to field going fire managers. It also provides detail about the fire behavior models and tools used to estimate fire ignition, spread/size, fireline intensity, and crown fire potential. The reference material contained within the guide will assist with decision support using various tools and methodologies. As new and improved safety zone research is obtained and available for distribution this guide will be updated to help house that information for the field communities.

As science and applications continued to increase within the fire behavior curriculum, the FBFRG was developed to help students learn fire behavior assessment and trainees retain the user skills needed in the field to successfully conduct fire behavior assessments. It is intended to be used in conjunction with the Fireline Handbook Appendix B Fire Behavior, PMS 410-2 (http://www.nwcg.gov/pms/pubs/410-2/appendixB.pdf).

It is the intention of the Fire Behavior Subcommittee to update the guide as necessary with the most recent science, and technologies for field use to help improve and assist with decision support, fire line safety and fire behavior interpretation.

YouTube videos will be uploaded periodically to provide additional supporting documentation for information found within this guide. These videos maybe found at: www.youtube.com/user/FireBehaviorSC

1. Weather

1.1 Forecasts

1.1.1 National Weather Service Products

Comprehensive Displays

NWS Fire Weather and Enhanced Data Display

URL: http://innovation.srh.noaa.gov/ridge2/fire/

About: *"The National Weather Service's (NWS) Experimental Enhanced Data Display (EDD) fills a void that currently exists in the NWS. It provides our partners and customers a single interface to access all things GIS related in the NWS. EDD is an extremely powerful and flexible GIS web application. Before the development of EDD, users had to navigate to countless web pages to get at the information they desired. EDD puts this information in one place making it very easy to display and manipulate this data. EDD is hosted on the National Internet Dissemination System (NIDS) and was developed by the Weather Ready Nation Pilot Project in Charleston, WV."*

NWS Weather Prediction Center (WPC)

URL: http://www.wpc.ncep.noaa.gov/index.php#page=ovw

About: Provides a source of a variety of forecast products including quantitative precipitation forecasts and discussions, short term and medium-range forecasts, surface analysis,

Short Term Forecast Products (1-7 Days)

NWS Routine Fire Weather Forecasts

URL: varies from region to region.

About: Updated generally twice a day, these narrative forecasts include a discussion of expected weather events, general weather parameters for the forecast zone over the next 48 hours and an outlook summary for days 3-5.

NWS Watches and Warnings

URL: http://www.weather.gov/

About: General site provides access point to different products with map emphasizing different watches and warnings. Issuance of a warning or watch implies stronger confidence levels in growth conditions between 12 to 96 hours ahead of an event.

NWS Spot Weather Forecasts

URL: https://www.weather.gov/spot/

About: "*This interface is intended to be used solely for the relay of forecast information to the National Weather Service. Submissions sent through this online form are intended for internal agency use."*

National Digital Forecast Database (NDFD)

URL: https://digital.weather.gov/ and http://wfas.net/nfdr/mapfiles/extract_ndfd_point_version2.php (CONUS only)

About: "The National Weather Service's NDFD graphic products are derived from a prescribed set of data contained within the NDFD (http://www.weather.gov/ndfd). These graphics are representations of the official NWS digital forecast. Forecast information for the Canadian portion of the Great Lakes is for informational purposes only and does not constitute an official forecast. In CONUS only, NDFD forecasts can be queried for individual latitude-longitude locations at http://wfas.net/nfdr/mapfiles/extract_ndfd_point_version2.php

NWS Storm Prediction Center

URL: http://www.spc.noaa.gov/

About: "*Provides timely and accurate forecasts and watches for severe thunderstorms and tornadoes over the contiguous United States. The SPC also monitors hazardous winter weather and fire weather events across the U.S. and issues specific products for those hazards."*

Extended Forecast Products (1 week to Several Months)

NWS Climate Prediction Center Extended Outlooks

URL: http://www.cpc.ncep.noaa.gov/

About: ***"****The Climate Prediction Center (CPC) is responsible for issuing seasonal climate outlook maps for one to thirteen months in the future. In addition, the CPC issues extended range outlook maps for 6-10 and 8-14 days as well as several special outlooks, such as degree day, drought and soil moisture, and a forecast for daily ultraviolet (UV) radiation index. Many of the outlook maps have an accompanying technical discussion."*

NWS Climate Prediction Center Expert Assessments

URL: http://www.cpc.ncep.noaa.gov/products/expert_assessment/

About: Includes Hazards Assessment, ENSO update, and others. Climate Prediction Center (CPC) meteorologists and oceanographers review climate and weather observations and data along with model results; assess their meaning, significance, and current status; and likely future climate impacts. Their findings are issued as assessments, advisories, special outlook discussions, and bulletins.

Drought Outlooks and Seasonal Climate Forecasts

URL: http://www.cpc.ncep.noaa.gov/products/Drought/

About: Shows predicted trends for areas experiencing drought depicted in the U.S. Drought Monitor, as well as indicating areas where new droughts may develop.

1.1.2 Forecast Models

National Centers for Environmental Prediction (NCEP) Model Guidance:

http://www.nco.ncep.noaa.gov/pmb/products/

Forecast Models

- Global Forecast Model (GFS):
- European Computer Forecast Model (ECMWF)
- North American Mesoscale Model (NAM)
- Canadian Model (CMC)
- Great Britain Computer Forecast (UKMET)
- High Resolution Rapid Refresh (HRRR)
- Weather Research & Forecasting (WRF)

Ensembles

*E*nsemble weather modeling techniques have been developed which include multiple outputs or forecast members from the same deterministic model but perturbed or initialized with different observed conditions. Forecast skill can increase the first two weeks of a forecast period using these ensemble modeling systems.

- Short Range Ensemble Forecast (SREF)
- Canadian Ensemble Forecasts (MSC)
- Global Ensemble Forecast System (GEFS)
- European Ensemble Prediction System (ENS)
- North American Multi-Model Ensemble (NMME)

High Resolution Rapid Refresh (HRRR) for Short Term Forecasts

URL: https://rapidrefresh.noaa.gov/hrrr/

About: The HRRR is a NOAA real-time 3-km resolution, hourly updated, cloud-resolving, convection-allowing atmospheric model, initialized by 3km grids with 3km radar assimilation. Radar data is assimilated in the HRRR every 15 min over a 1-h period adding further detail to that provided by the hourly data assimilation from the 13km radar-enhanced Rapid Refresh .

North American Multi-Model Ensemble (NMME) for Long range forecasts

URL: http://www.cpc.ncep.noaa.gov/products/NMME/about.html

About: The NMME is an experimental multi-model seasonal forecasting system consisting of coupled models from US modeling centers including NOAA/NCEP, NOAA/GFDL, IRI, NCAR, NASA, and Canada's CMC. The multi-model ensemble approach has proven extremely effective at quantifying prediction uncertainty due to uncertainty in model formulation, and has proven to produce better prediction quality (on average) than any single model ensemble.

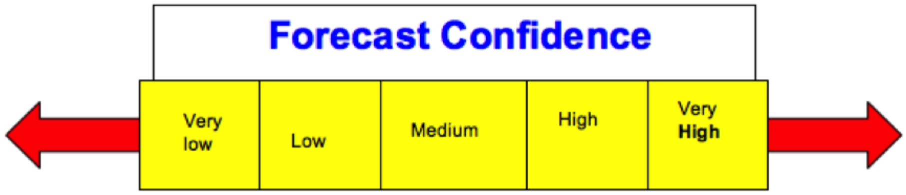
1.1.3 Forecast Drivers

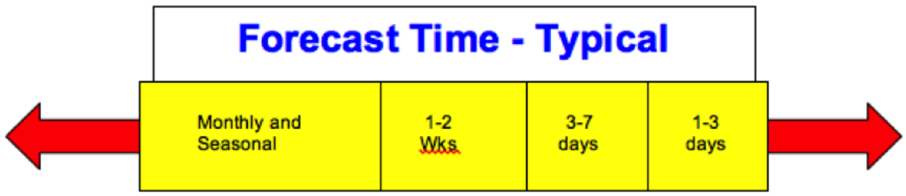
Teleconnections and Forcing Mechanisms

Coupled oceanic-atmospheric forcing mechanisms	Usefulness and Definition	Confidence Impact
El Nino-Southern Oscillation (ENSO)	Irregular periodic variation in winds and sea surface temperature over tropical eastern Pacific. Warming phase is El Nino and cooling phase is La Nina. There is also an ENSO neutral condition. Deep thunderstorm development over the eastern equatorial Pacific will help alter the jet stream and make more moisture available for Pacific storm systems that impact the USA.	Warm or cool phases combined with other climate drivers such as certain phases of the PDO can lead to higher confidence long term outlooks.
Pacific Decadal Oscillation (PDO)	A longer lived northern Pacific climate variability that has a negative and positive phase. The jet stream will tend to dip further south over the western United States under a positive phase and move further north under a negative phase.	Positive or negative phases to the PDO combined with other climate drivers such as ENSO conditions can lead to higher confidence long term outlooks.
Pacific Meridional Model (PMM)	Describes the interaction between ENSO and PDO teleconnections and has a negative and positive phase	Determining positive or negative phases of the PMM may help resolve the Spring Barrier issue and ENSO prediction. This should help lead to higher confidence outlooks originating during the months of April through June.
Modoki	Alternation in normal La Nina and El Nino SST patterns across the tropical Pacific thus disrupting typical teleconnection patterns. “This isn’t your grandfather’s El Nino”.	Confidence becomes varied and can be less depending on other coupled ocean-atmosphere phenomena
Madden Julian Oscillation (MJO)	MJO is a tropical disturbance that propagates eastward around the global tropics with a cycle on the order of 30 to 60 days. They typically are most active during late fall, winter and early spring period. MJO can influence ENSO tendencies.	Active MJO’s can increase forecast confidence for certain weather anomalies across USA.
Aleutian Low	Strength of the Aleutian low combined with PMM modes can accentuate or dampen MJO impacts on the jet stream position and storm track across western USA.	Confidence of an active storm track across western US increases when the Aleutian low is stronger than average and combines with a positive PMM and a MJO is present.

1.1.4 Forecast Confidence

The typical "Confidence Horizon" for an application requiring forecast information with 'Very High' confidence/accuracy is about three days. What is critical is that there are frequent shifts in this relationship that both expand and contract the amount of time that 'Very High' skill is available, thus changing the Confidence Horizon.





This is especially helpful when choosing the appropriate analysis tool in WFDSS (Near-term, Short-term or FS Pro) or applying the weather forecast within them. The concept is also helpful when placing explanations in the analysis or incident notes section of WFDSS.

The atmosphere is chaotic but sometimes there is rhythm in the chaos. Climate outlook scientists study coupled oceanic and atmospheric forcing mechanisms like the El Nino Southern Oscillation (ENSO) cycle and Madden Julian Oscillation (MJO). These forcing mechanisms are tied to several teleconnection or long range-long term correlated weather patterns that determine meteorological impacts across North America.

Forecast skill typically goes up (i.e. rhythm in the chaos) in the mid and long term when certain forcing mechanisms and teleconnection patterns align thus adjusting the normal Confidence Horizon. Under these circumstances, a monthly or seasonal outlook can have Medium to sometimes High confidence for certain weather patterns such as warmer and drier conditions and sometimes frequent wind events. This is a shift from Low to Very Low confidence under normal situations for longer range forecasts.

Other teleconnection alignments can lead to mixed atmospheric forcing signals thus leading to unusually low confidence periods (i.e. conflicting rhythm).

NWS Area Forecast Discussion

URL: http://forecast.weather.gov/product_sites.php?site=CRH&product=AFD

About: "*This National Weather Service product is intended to provide a well-reasoned discussion of the meteorological thinking which went into the preparation of the Zone Forecast Product. The forecaster will try to focus on the most particular challenges of the forecast. The text will be written in plain language or in proper contractions. At the end of the discussion, there will be a list of all advisories, non-convective watches, and non-convective warnings. The term non-convective refers to weather that is not caused by thunderstorms. An intermediate Area Forecast Discussion will be issued when either significant forecast updates are being made or if interesting weather is expected to occur."*

1.2 Observing Fire Weather

Take time to review forecasts and make good fireline observations and monitor automated weather stations to ensure effective forecasts and briefings. Each Single Resource (crew, squad, and individual) is responsible for insuring that they *"keep informed of fire weather conditions and forecasts"* so that they may *"base all actions on current and expected behavior of the fire."* ***The process includes obtaining and reviewing latest forecasts, taking observations to validate them through the assignment, reporting what is learned to those who need the information, and requesting forecast updates.***

1.2.1 Fire Weather Apps

Fire Weather Calculator http://firecenter.umt.edu/weather-app/default.php

Dark Sky https://darksky.net/app/

Sunrise – sunrise and sunset calculator http://www.adairsystems.com/sunrise/

Weather Underground https://www.wunderground.com/wundermap

1.2.2 Fireline Observations

Location and Timing of Fireline Weather Observations

Four times during a 24-hour day stand out as valuable for assessing forecasts and evaluating thresholds associated with fire behavior transitions.

- An early morning observation that represents time and conditions when the minimum temperature and maximum humidity occur.
- A late afternoon observation that represents the time and conditions when the maximum temperature and minimum humidity occur.
- At the times when active fire behavior seems to increase and diminish during the burn period.
- Other times, for example hourly throughout the afternoon or when changes occur, may be called for by fireline supervisors or dictated by changing conditions to ensure situational awareness.

Regardless of whether the fire is a prescribed fire project or a wildfire, the weather observer should strive to pick observation sites that most accurately reflect environmental conditions around the fire's location.

- Decide whether a ridgetop, midslope, or drainage bottom location is most representative.
- If on a slope, the aspect and slope steepness is an important consideration.
- Consider what is a representative fuelbed for the fire.
- Attempt to find a safe site upwind or on the flank of the fire. Generally, well ventilated areas in the shade are desirable locations for the observation.
- Minimize the fire's influence on your observation. Avoid taking observations in the black. Avoid observations affected by gusty indraft breezes and radiant heat from the fireline

Note the type of instruments used

It's a good idea to remark whether the observations were made with an electronic weather sensor or traditional sling psychrometer. Electronic temperature and humidity sensors should regularly be calibrated against weather instruments of reliable accuracy. Check that the batteries are fresh

Communicate and Document the Weather Observation

The most accurate weather observation is of little use unless it is properly communicated in a timely fashion to those who need it. Make sure that current observations are reported verbally over the radio to insure situational awareness.

- Follow instructions for periodic radio reports to fireline supervisors and/or incident communications unit.
- Report measurements with trends, such as temperature 75 – up 5 degrees from last hour.

Provide written documentation of weather observations to fireline supervisor, situation unit, incident meteorologist, or the local Weather Forecast Office. Retain a copy for your records. Don't assume that weather observations are automatically being received by the proper users. The weather observer may need to take the initiative to verify that the information is being passed up the line. Forms are available.

1.2.3 Wind Observations and Estimations; Calibrating Forecast/Prediction

Get forecast from Incident Meteorologist or Fire Weather Forecaster

Because windspeed and direction is the most variable weather factor over the duration of an assignment, the observer will be concerned with adjusting and validating forecasted winds as much as measuring current windspeed. It is difficult for a meteorologist to produce localized wind forecasts, especially if the wind is influenced by terrain features. Forecasted winds will frequently need adjustment because they are representing a wind other than mid-flame, such as ridgetop or surface winds. See the definitions in section 1.2. It will be important to communicate with the meteorologist the factors that influence the wind measurements that are provided.

Use Surface Wind Estimation Worksheet

Report observation type or height. Identify sheltering and aspect/slope position for the wind observation. And indicate whether local winds are influencing the observation.

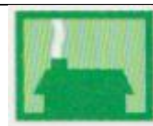
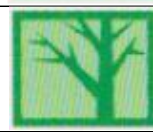
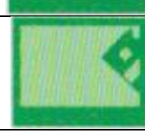
Consider possibility of Critical Wind

Estimate or validate 20-ft surface windspeed

If the weather forecast product provides windspeed as "free air or ridgetop" or if winds in the fire area are influenced by local winds, it may be necessary to use the form in section 1.2.3 to estimate the surface/20 ft windspeed.

- ***Identify speed and direction of any forecast critical wind.***
- ***Determine speed and direction of any Local Winds***
- ***Determine speed and direction of General Winds and whether they will influence the 20-ft wind.***
- ***Combine factors above into an estimate of local surface (20-ft) windspeed.***

Visual Surface (20-ft) Wind Estimate – Modified Beaufort Scale

Class	Windspeed	Terminology		Visible Effect
0	**Less than 1 mph**	**Calm**		Calm, Smoke rises vertically
1	**1 to 3 mph**	**Very Light Breeze**		Leaves of quaking aspen in constant motion; small branches, tall grasses and weeds sway, wind vane barely moves
2	**4 to 7 mph**	**Light Breeze**		Trees of pole size in the open sway gently, Wind felt distinctly on face; leaves rustle; wind flutters small flag
3	**8 to 12 mph**	**Gentle Breeze**		Leaves, small twigs in constant motion; Tops of trees in dense stands sway; light flags extended
4	**13 to 18 mph**	**Moderate Breeze**		Trees of pole size in the open sway violently; whole trees in dense stands sway noticeably; dust is raised in the road.
5	**19 to 24 mph**	**Fresh Breeze**		Branchlets are broken from trees; inconvenience is felt in walking against wind
6	**25 to 31 mph**	**Strong Breeze**		Tree damage increases with occasional breaking of exposed tops & branches; difficult walking against wind.
7	**32 to 38 mph**	**Moderate Gale**		Severe damage to tree tops; very difficult to walk into wind; significant structural damage occurs.
8	**39 to 46 mph**	**Fresh Gale**		Surfaced strong Santa Ana; intense stress on all exposed objects, vegetation, buildings; canopy offers little protection
9	**47 to 54 mph**	**Strong Gale**		Slight structural damage occurs; slate blown from roofs
10	**55 to 63 mph**	**Whole Gale**		Seldom experienced on land; trees broken; structural damage occurs
11	**64 to 72 mph**	**Storm**		Very rarely experienced on 12land; usually with widespread damage
12	**73 mph or more**	**Hurricane Force**		Violence and destruction

Estimate or validate Midflame Windspeed

Eye level windspeed is usually assumed to be the same as mid-flame windspeed. However, as suggested in the Fireline Assessment Method (FLAME) reference, it may be too low for flames in shrub fuels and too high for flames in forest litter. In any case, it may be necessary to adjust forecasted 20 ft winds or observed mid-flame windspeed to make comparisons and validate forecasts.

Observing eye-level windspeed in the field*:*

The observer should take care to face directly into the wind and closely observe the wind speed indicator fluctuations. Exposure to sunlight is not a concern during the wind observation.

- An eye level wind speed measurement requires at least one full minute of sampling and preferably more.
- Note time and rapidity of transitions in diurnal winds
- When using a Dwyer tube, mentally average the wind speed and note the peak gust during the sampling period.
- Electronic sensors make wind averaging and gust measurement easy. They are more accurate and are preferred for eye level wind speed observations.
- Remember: The wind direction is defined as the direction the wind is coming from.

Estimate Effective Windspeed for slope influence

The influence of slope on fire spread is applied as a slope-equivalent “windspeed”.

Where slope is significant (generally 20% or more), all the fire behavior assessment tools in section 5 (FLAME, Lookup Tables, Nomograms & Nomographs, and BehavePlus) provide means for estimating “effective windspeed”.

This adjusted windspeed should be used instead of the mid-flame windspeed estimate in fire behavior predictions.

1.2.4 Temperature and Humidity Observation

Estimating temperature, relative humidity and dewpoint can provide insight to critical fire behavior thresholds for ignition and crown fire potential.

Sling Psychrometer Use

The following are instructions for determining wet and dry bulb temperatures using the sling psychrometer. These instructions are based on those from page 259 of the S-290 Instructors Manual. Several additional comments have been added.

1. If your sling has been in your pack, you may need to hang it in a tree, in the shade, to let it adjust to the outside air temperature. This may be a good time to take the wind observation.
2. Stand in a shaded, open area away from objects that might be struck during whirling. If in open country, use your body shade to shade the psychrometer. If possible, take your weather observations over a fuel bed that is representative of the fuels that the fire is burning in. Stay away from heat sinks.
3. Face the wind to avoid influence of body heat on the thermometers.
4. Saturate the wick of the wet bulb with clean, mineral free water (distilled if available) at air temp.
5. Ventilate the thermometers by whirling at full arm's length. Your arm should be parallel to the ground. Whirl for 1 minute.
6. Note the wet bulb temperature. Whirl for another 40 or 50 times and read again. If the wet bulb is lower than the first reading, continue to whirl and read until it will go no lower. Read and record the lowest point. If the wet bulb is not read at the lowest point, the calculated relative humidity will be too high. Calculate dew point each time. If it is changing significantly it may suggest a bad observation.
7. Read the dry bulb immediately after the lowest wet bulb reading is obtained.
8. Determine the relative humidity from the tables.

Important Tips: Sometimes beginners do not take accurate psychrometer readings because of the following common mistakes:

- Changing psychrometers from one observation to the next. Try and use same one throughout.
- not ventilating the psychrometer long enough to reach equilibrium;
- not getting the wick wet enough, or letting it dry out;
- holding it too close to the body or taking too long to read the thermometers;
- touching the bulb ends with the hands while reading;
- Not facing into the breeze.

Estimating RH & Dew Point from Psychrometric Tables

Psychrometric tables included in the belt weather kit or provided here allow you to estimate Relative Humidity and Dew Point from Dry Bulb and Wet Bulb Temperatures obtained in the field.

1. Find the correct table based on elevation at your observing location
2. Use your DB Temp and WB Temp to find the intersecting cell on the page
3. Read the resulting RH (below) and Dew Point (above) in that cell.

Example Table

Each Table is labeled with an Elevation Range, including an adjustment for Alaska use.

Dry Bulb Temperature is located on the left axis and the wet bulb temp is located at the top of each column. Cell at their intersection includes the resulting RH and Dew Point.

Elevations between 1,901 and 3,900 feet

Wet Bulb Temperatures 39 to 79 F (Read Down)

Dry Bulb Temperatures 61 to 80 F (Read Across)

DP / RH

Dry Bulb	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
61	-17/4	-3/7	6/11	12/14	18/18	22/22	26/26	29/30	33/34	35/38	38/42	40/47	43/51	45/56	47/60	49/65	51/69	53/74	55/79	56/84	58/89	59/95																			
62	-31/2	-9/5	2/9	9/12	15/16	20/20	24/23	28/27	31/31	34/35	37/39	39/43	42/48	44/52	46/56	48/61	50/65	52/70	54/75	56/80	57/85	59/90	60/95																		
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66			-32/1	-9/4	2/8	10/11	16/14	21/17	25/21	29/24	32/28	35/31	38/35	40/39	43/43	45/47	47/51	49/55	51/59	53/63	55/67	57/72	58/76	60/81	61/85	63/90	65/95														
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68				-32/1	-9/4	2/7	10/10	16/13	21/17	25/20	29/23	32/26	35/30	38/33	41/37	43/41	45/44	48/48	50/52	52/56	54/60	55/64	57/68	59/72	60/77	62/81	64/86	65/90	67/95												
69					-17/3	-3/6	7/9	13/12	19/15	23/18	27/21	31/24	34/27	37/31	40/34	42/38	45/41	47/45	49/49	51/53	53/56	55/60	56/64	58/69	60/73	62/77	63/81	65/86	66/91	68/95											
70					-31/1	-9/4	3/7	10/10	16/13	21/16	26/19	29/22	33/25	36/28	39/32	41/35	44/39	46/42	48/46	50/49	52/53	54/57	56/61	58/65	59/69	61/73	63/77	64/82	66/86	67/91	69/95										
71						-17/3	-2/5	7/8	14/11	19/14	24/17	28/20	31/23	35/26	38/29	40/33	43/36	45/39	47/43	49/46	51/50	53/54	55/58	57/61	59/65	60/69	62/73	64/78	65/82	67/86	68/91	70/95									
72						-30/1	-8/4	3/7	11/9	17/12	22/15	26/18	30/21	33/24	36/27	39/30	42/34	44/37	46/40	49/44	51/47	53/51	55/54	56/58	58/62	60/66	62/70	63/74	65/78	66/82	68/86	69/91	71/95								
73							-16/3	-1/5	8/8	15/11	20/13	24/16	28/19	32/22	35/25	38/28	41/31	43/34	46/38	48/41	50/44	52/48	54/51	56/55	58/59	59/62	61/66	63/70	64/74	66/78	67/82	69/87	70/91	72/95							
74							-28/1	-7/4	4/6	12/9	18/12	23/14	27/17	31/20	34/23	37/26	40/29	42/32	45/35	47/38	49/42	51/45	53/48	55/52	57/55	59/59	61/63	62/67	64/70	65/74	67/78	68/83	70/87	71/91	73/95						
75								-14/3	0/5	9/8	15/10	21/13	25/16	29/18	33/21	36/24	39/27	41/30	44/33	46/36	48/39	51/42	53/46	55/49	56/52	58/56	60/60	62/63	63/67	65/71	66/75	68/79	69/83	71/87	72/91	74/96					
76								-26/1	-6/4	5/6	13/9	18/11	23/14	27/17	31/19	35/22	38/25	40/28	43/31	45/34	48/37	50/40	52/43	54/46	56/50	58/53	59/57	61/60	63/64	64/67	66/71	68/75	69/79	70/83	72/87	73/91	75/96				
77								-54	-13/3	1/5	9/7	16/10	21/12	26/15	30/18	33/20	36/23	39/26	42/29	45/32	47/34	49/37	51/41	53/44	55/47	57/50	59*/54	61/57	62/61	64/64	66/68	67/71	69/75	70/79	71/83	73/87	74/91	76/96			
78									-23/1	-4/4	6/6	13/9	19/11	24/13	28/16	32/19	35/21	38/24	41/27	44/29	46/32	48/35	51/38	53/41	55/44	56/48	58/51	60/54	62/57	63/61	65/64	67/68	68/72	70/76	71/79	73/83	74/87	75/91	77/96		
79									-45	-11/3	2/5	10/7	17/10	22/12	27/14	30/17	34/20	37/22	40/25	43/27	45/30	48/33	50/36	52/39	54/42	56/45	58/46	60/51	61/55	63/58	65/61	66/65	68/68	69/72	71/76	72/80	74/84	75/88	76/92	78/96	
80										-20/2	-3/4	7/6	14/8	20/11	25/13	29/15	33/18	36/20	39/23	42/26	44/28	47/31	49/34	51/37	53/40	55/43	57/46	59/49	61/52	62/55	64/58	66/62	67/65	69/69	70/72	72/76	73/80	75/84	76/88	77/92	79/96

Adjusting RH for changes in Temperature and Elevation

Under certain circumstances, it may not be possible to estimate relative humidity for a particular elevation. It may also be necessary to make field adjustment to forecasted relative humidity for some time later in the burn period. In both cases, given that the air mass is unchanging and fairly neutral, it is possible to use current estimates of dew point and temperature and to make adjustments in both cases:

Case 1: **Estimate relative humidity for an elevation above or below the observation**; assuming an average lapse rate of approximately 4° F, increase the temperature by 4° F for each 1000 ft drop in elevation or decrease it by 4° F for each 1000 ft increase in elevation. Using the new temperature and the estimated dew point, look up the new relative humidity in the appropriate psychometric table.

Case 2: **Validate a forecasted relative humidity;** using the estimated dew point and the forecasted temperature, look up the new relative humidity in the appropriate psychometric table.

Vapor Pressure Deficit (VPD)

While Relative Humidity refers to the amount of water vapor in the air as a percentage of saturation levels, Vapor Pressure Deficit represents an absolute measure of the difference between the moisture in the air and the amount it could hold when saturated.

VPD rises as the moisture deficit increases and may seem counter-intuitive for users comfortable using RH. It follows a seasonal trend of low levels in the winter and higher levels during the warm summer months, controlled by variation in temperature and atmospheric humidity.

VPD can provide important insight about the role of ambient temperature as well as atmospheric humidity. For example, at low temperatures a low RH will not be accompanied by significantly high VPD levels. But that same low RH under high temperatures will produce elevated VPD. The table below here provides an example interpretation.

		Relative Humidity, in %																			
Temp (°C)	Temp (F)	100	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5
0	32	0	0	1	1	1	2	2	2	2	3	3	3	4	4	4	5	5	5	5	6
2	36	0	0	1	1	1	2	2	2	3	3	4	4	4	5	5	5	6	6	6	7
4	39	0	0	1	1	2	2	2	3	3	4	4	4	5	5	6	6	7	7	7	8
5	41	0	0	1	1	2	2	3	3	3	4	4	5	5	6	6	7	7	7	8	8
6	43	0	0	1	1	2	2	3	3	4	4	5	5	6	6	7	7	7	8	8	9
7	45	0	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10
8	46	0	1	1	2	2	3	3	4	4	5	5	6	6	7	8	8	9	9	10	10
9	48	0	1	1	2	2	3	3	4	5	5	6	6	7	7	8	9	9	10	10	11
10	50	0	1	1	2	2	3	4	4	5	6	6	7	7	8	9	9	10	10	11	12
11	52	0	1	1	2	3	3	4	5	5	6	7	7	8	9	9	10	10	11	12	12
12	54	0	1	1	2	3	4	4	5	6	6	7	8	8	9	10	11	11	12	13	13
13	55	0	1	1	2	3	4	4	5	6	7	7	8	9	10	10	11	12	13	13	14
14	57	0	1	2	2	3	4	5	6	6	7	8	9	10	10	11	12	13	14	14	15
15	59	0	1	2	3	3	4	5	6	7	8	9	9	10	11	12	13	14	14	15	16
16	61	0	1	2	3	4	5	5	6	7	8	9	10	11	12	13	14	15	15	16	17
17	63	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	15	16	17	18
18	64	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	17	18	19	20
19	66	0	1	2	3	4	5	7	8	9	10	11	12	13	14	15	16	18	19	20	21
20	68	0	1	2	4	5	6	7	8	9	11	12	13	14	15	16	18	19	20	21	22
21	70	0	1	2	4	5	6	7	9	10	11	12	14	15	16	17	19	20	21	22	24
22	72	0	1	3	4	5	7	8	9	11	12	13	15	16	17	19	20	21	22	24	25
23	73	0	1	3	4	6	7	8	10	11	13	14	15	17	18	20	21	22	24	25	27
24	75	0	1	3	4	6	7	9	10	12	13	15	16	18	19	21	22	24	25	27	28
25	77	0	2	3	5	6	8	10	11	13	14	16	17	19	21	22	24	25	27	29	30
26	79	0	2	3	5	7	8	10	12	13	15	17	18	20	22	24	25	27	29	30	32
27	81	0	2	4	5	7	9	11	12	14	16	18	20	21	23	25	27	29	30	32	34
28	82	0	2	4	6	8	9	11	13	15	17	19	21	23	25	26	28	30	32	34	36
29	84	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38
30	86	0	2	4	6	8	11	13	15	17	19	21	23	25	28	30	32	34	36	38	40
31	88	0	2	4	7	9	11	13	16	18	20	22	25	27	29	31	34	36	38	40	43
32	90	0	2	5	7	10	12	14	17	19	21	24	26	29	31	33	36	38	40	43	45
33	91	0	3	5	8	10	13	15	18	20	23	25	28	30	33	35	38	40	43	45	48
34	93	0	3	5	8	11	13	16	19	21	24	27	29	32	35	37	40	43	45	48	51
35	95	0	3	6	8	11	14	17	20	22	25	28	31	34	37	39	42	45	48	51	53
36	97	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	50	53	56
37	99	0	3	6	9	13	16	19	22	25	28	31	35	38	41	44	47	50	53	56	60
38	100	0	3	7	10	13	17	20	23	26	30	33	36	40	43	46	50	53	56	60	63
39	102	0	3	7	10	14	17	21	24	28	31	35	38	42	45	49	52	56	59	63	66
40	104	0	4	7	11	15	18	22	26	29	33	37	41	44	48	52	55	59	63	66	70

Vapor Pressure Deficit in Millibars by Temperature and Relative Humidity. Green (VPD 5-12) represents good growing conditions. Boxes represent "crossover" combinations for Temp & RH.

Long used in greenhouse and agricultural applications, it is a good indicator of the moisture stress experienced by green vegetation. The new Growing Season Index (GSI) uses it as a key criterion to greenup and curing phenology. GSI considers VPD of 9 mb optimum growing conditions.

The ***"crossover"*** concept (Alberta Forest Service 1985) refers to rising temperature (in °C) and falling RH reaching the point where they are equal (highlighted boxes in the table). Interpretations suggest the onset of potential for extreme fire behavior.

1.2.5 Sky Observations

Airport Webcams: http://airportwebcams.net/airport-webcams-by-time-zone/

Synoptic (Large Scale) forecasts and representations of current conditions include reference to the relative stability of the atmosphere in the area. In that vein, there are numerous indicators that can be reviewed and interpreted. Several are referenced in section 1.4.

However, these general atmospheric conditions are influenced by the terrain and other local factors to produce more localized effects. The weather observer can provide important information to meteorologists by reporting the visual cues and the timing of changes throughout the day.

These visual cues are generally associated with a weather observation by recording them in the remarks column so that they get a time stamp.

Usually, if a visual cue is worth noting with the weather observation, photography can be very valuable supporting documentation. If a photo is taken, use a photo log or reference the photo number with the location date, time and other identifying comments.

Here are some important examples:

Lightning and Wind

- ***Lightning*** should be reported immediately to alert fireline supervisors to take appropriate precautions and to cue meteorologists to review their lightning detection tools.
- ***Sudden wind shifts*** may be important indicators of breaking inversions or frontal passage.

Smoke, Dust, and Fire

- ***Rising smoke column*** indicates neutral or instable conditions. ***Flattening column*** indicates inversion at that point.
- ***Smoke column change direction as it rises*** indicates wind shear or local wind influence.
- ***Smoke column developing a pyrocumulus cap cloud*** indicates strong instability and impending down drafts.
- ***Haze and poor visibility*** are indicators of inversions. Is this localized (night-time inversion) or more general and persisting throughout the day. Note if and when the haze or poor visibility abates during the burn period as indicator of increase in fire behavior.
- ***Dust clouds*** radiating away from thunderstorms indicate potentially dangerous downdrafts.
- ***Dust devils*** are important indicators of surface instability.
- ***Firewhirls*** occur due to extreme vertical motion in a wildfire's convection column. Be aware of the potential for gusty erratic winds when firewhirls are observed. A stable atmosphere generally tends to limit violent vertical motion. As a result, cloud buildups during stable conditions tend to be wider and flatter, possibly covering much of the sky. It should be noted that strong general winds are possible during stable conditions depending upon the weather pattern. The firefighter should pay attention to the fire weather forecast and keep an eye on the sky for indicators of potential severe conditions that can dominate the fire environment.

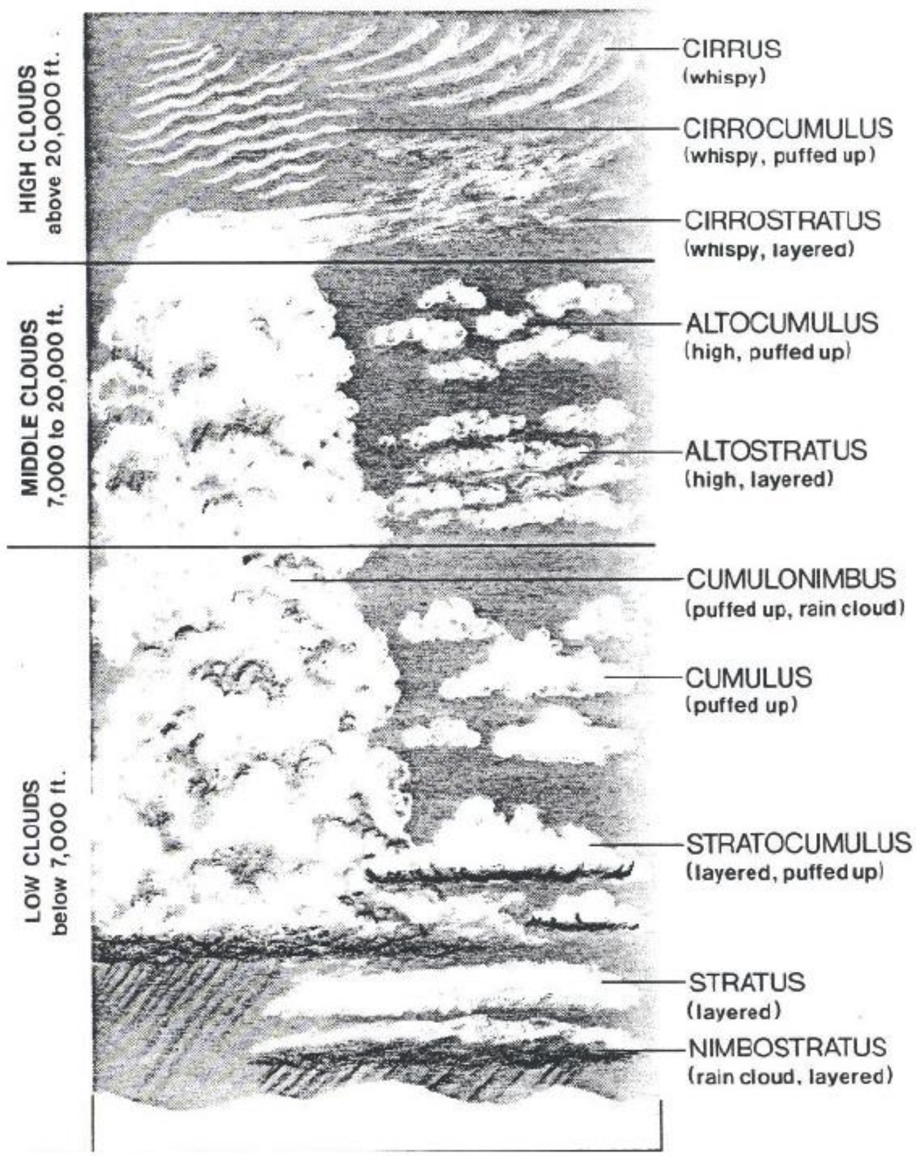
Clouds, Fog, & Precipitation (from John Saltenberger)

Clouds occur when moisture in the atmosphere condenses into visible droplets or ice crystals. This usually occurs when moist air becomes cooled by lifting. The shape and texture of clouds reveals much about whether the lifting process has been gradual and gentle or rapid and potentially violent.

Paying attention to the sky can help the firefighter stay aware of the current fire environment as well as anticipation of potential changes.

- ***Cloud Cover, in percent***, is an important input for fuel moisture shading.
- ***Building cumulus, towering cumulus, or thunderstorms*** are all indicators of significant instability that is probably already influencing surface winds.
- ***Showers or virga*** may be indicators of instability.

The NWCG cloud chart depicts sky signs of interest for wildland firefighters that are valuable tools in revealing the atmosphere's current state as well as foretelling potential changes. Clouds are an important indicator of stability.

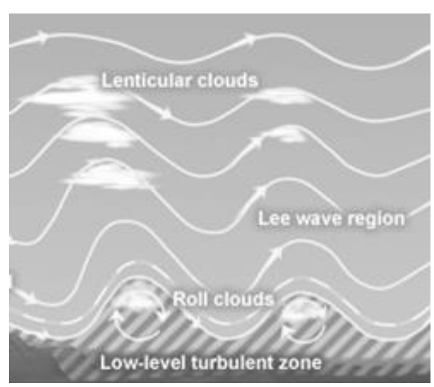


Clouds that reveal variations of instability in the atmosphere:

- ***Cumulus*** (several varieties): Weak instability. Normally not a concern for firefighters. However, when cumulus continues growing, firefighters are advised to keep an eye on the buildups due to the potential for sudden downdrafts and gusty winds.
- ***Alto Cumulus*** (several varieties, e.g. castellanus): Upper atmosphere instability and possible weather change. These indicate increasing moisture and instability with the potential for thunderstorms.
- ***Cumulonimbus***: Very unstable. Fully developed mature thunderstorms contain extreme vertical motion and the strong likelihood of gusty, erratic winds that can arise suddenly miles away from the cloud buildup. Localized wind gusts over 100 mph are possible with very strong thunderstorms along with lightning, virga, and hail. Very strong thunderstorms may also be accompanied by shelf clouds or tornados. Clearly, cumulonimbus clouds portend many hazards to the firefighter exposed on the fireline.
- ***Pyrocumulus***: Very unstable. Pyrocumulus clouds grow above ongoing wildfires drawing energy from the heat of combustion and condensation of moisture in the fire's convection column. A white-capped pyrocumulus cloud is a concern for firefighters for the same reason as a thunderstorm: Strong, gusty erratic winds can arise suddenly near a pyrocumulus. Virga, light raindrops, and even some lightning is possible with well-developed pyrocumulus clouds.

Clouds that indicate a stable atmosphere:

- ***Stratus*** (several varieties): Stable and moist. Stratus clouds can cover much of the sky and blot out sunlight or even bring rain. Stratus clouds tend to mean higher humidity and decreased fire behavior. Normally not a concern for firefighters.
- ***Cirrostratus*** (several varieties): High level stratus clouds formed of ice crystals. Cirrostratus clouds are normally not a concern for firefighters. However, if these clouds increase from the west or northwest, a front may soon be approaching with strengthening general winds. Check the fire weather forecast.
- ***Altostratus*** (several varieties): Mid to high level stratus clouds that are a good indicator of an approaching front with strengthening general winds. Check the fire weather forecast.
- ***Wave cloud or Lenticular cloud***: Smooth almond- shaped clouds that sometimes form over mountainous terrain in patterns similar to stacked dishes. These clouds tend to remain fixed over one peak and are ***a good indicator of strong general winds in the upper atmosphere that may descend to the surface.*** Wave clouds are sometimes seen during foehn wind events. Check the fire weather forecast



1.2.6 Automated Weather Stations

A wide variety of weather observing networks are available. Many of them can be observed from a variety of websites, such as:

- http://mesowest.utah.edu/ provides many of the same tools that ROMAN used to.
- Weather Underground provides observations from websites and web apps.
- Iowa Environmental Mesonet provides access to current and historic data.

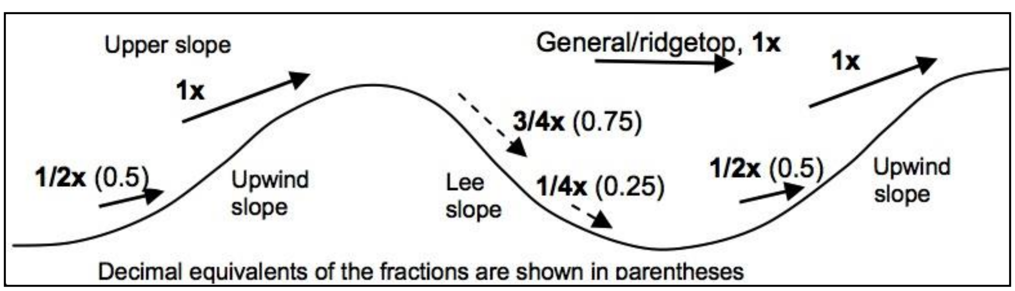
Networks of Interest

- ***Remote Automated Weather System (RAWS)*** are sited to assist land management agencies with monitoring air quality, fire weather, and in support of research applications. There are a variety of standards, though the fire weather stations adhere to a different standard called for by the National Fire Danger Rating System (NFDRS).
- ***Incident Remote Automatic Weather Stations (IRAWS)*** are intended for use on or near the fireline, and can be rapidly relocated as desired by Fire Behavior Analysts (FBAs) or Incident Meteorologists (IMETs) to provide timely weather data. Fire Managers, FBAs and IMETs use IRAWS data to predict fire behavior, prescription burning times, fire weather forecasting, and canyon and ridge top winds. Generally, like RAWS equipment, mast heights may vary.
- ***Automated Surface Observing System (ASOS)*** and ***Automated Weather Observing System (AWOS)*** stations located generally near airports to serve aviation needs. ASOS stations also serve as a primary climatological observing network. They adhere to international standards for weather observations.
- A wide variety of other station networks are available and may be appropriate for local and ad hoc uses.

Wind Observations from Automated Sensors

Generally, four factors govern the surface wind estimate produced by automated weather observing sensors.

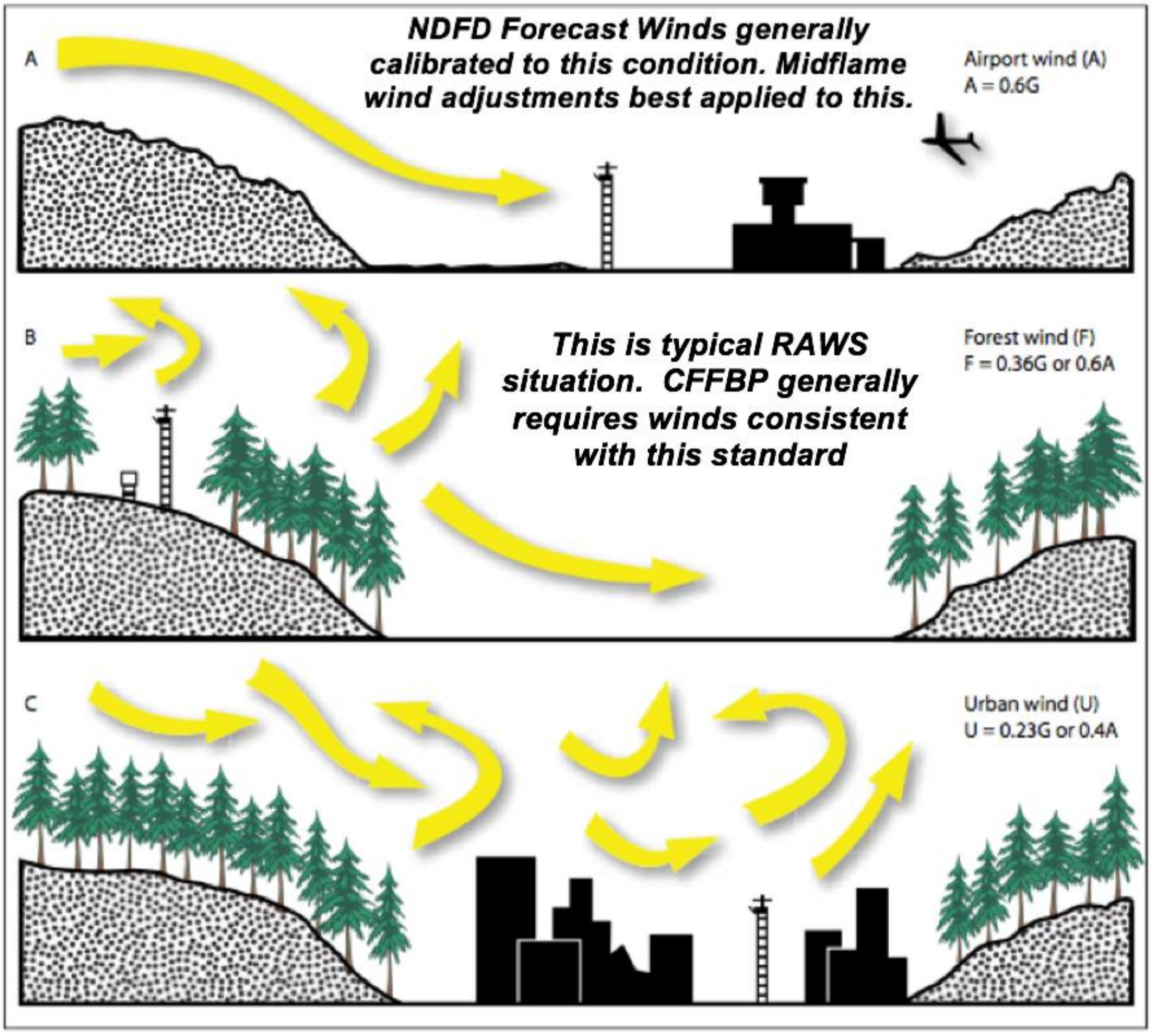
- Local terrain influences on the general winds at any location due to exposure and differential surface heating related to slope, water and ice factors and channeling of general winds or air flow. Image here demonstrates the effect of terrain on wind measurements in different locations (Bishop, 2010).



- Sensor standards for timing and duration of observation. For example, fire weather standard averages windspeed over 10 minutes while International standard averages windspeed over 2 minutes.

- Surface characteristics that produce differing friction factors (trees and buildings vs airports and agricultural regions). See figure on next page.

Generally, gradient winds are reduced by friction from the earth's surface. The surface friction in areas surrounded by large flat smooth surfaces (airports and agricultural areas) is less than that experienced in forest openings and in cities. (Lawson & Armitage, 2008)



- Sensor height above the prevailing cover.

A "rough" surface represents forest clearings covered in low brush or slash whereas the "smooth" surface is used for clearings where the ground is smooth or covered in mowed grass or cropped brush. (Lawson & Armitage, 2008)

Wind speed adjustment factors for anemometer mast height less than 12 m

	Adjustment factor	
Mast height (m)	Rough surface	Smooth surface
1.5	1.94	1.48
2.0–2.9	1.54	1.31
3.0–3.9	1.37	1.22
4.0–4.9	1.26	1.16
5.0–6.9	1.18	1.11
7.0–8.9	1.06	1.03
9.0–11.9	1.00	1.00

1.3 Critical Fire Weather

1.3.1 Summary

Synthesis of Knowledge of Extreme Fire Behavior: Volume 1 for Fire Managers, Chap. 3 (https://www.fs.fed.us/pnw/pubs/pnw_gtr854.pdf)

The four critical weather elements that produce extreme fire behavior are ***low relative humidity, strong surface wind, unstable air, and drought****. [The] Critical fire weather patterns [that support these conditions] can be separated into two primary categories; those that produce strong surface winds and those that produce atmospheric instability. In both cases, an unusually dry airmass, for the region and season, must also occur. In brush and timber fuels, drought becomes an important precursor by increasing fuel availability.*

Most periods of critical fire weather occur in transition zones between high- and low-pressure systems, both at the surface and in the upper air. The surface pressure patterns of most concern are those associated with cold fronts and terrain-induced foehn winds. ***Cold front passages*** *are important to firefighters because of strong, shifting winds and unstable air that can enhance the smoke column or produce thunderstorms****.*** ***Foehn winds*** *occur on the lee side of mountain ranges and are typically very strong, often occurring suddenly with drastic warming and drying. The area between the upper ridge and upper trough has the most critical upper air pattern because of unstable air and strong winds aloft that descend to ground level.*

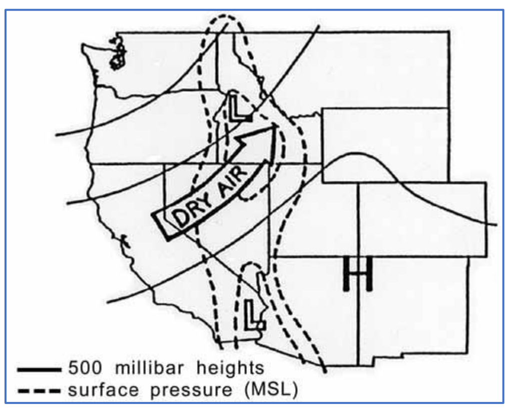
East of the Rocky Mountains, most critical fire weather patterns are associated with the periphery of high-pressure areas, particularly in the prefrontal and postfrontal areas.

- *In the northern plains, Great Lakes, and the Northeastern US*, prefrontal high pressure from the Pacific, Northwestern Canada, and Hudson Bay all can produce very dry conditions. Cold fronts produce relatively short lived periods of high winds and instability that can produce extreme fire behavior.
- *In the Southeastern US,* drought is frequently associated with the La Niña state of the southern oscillation pattern or a blocking ridge aloft near the Atlantic coast. Often critical weather patterns follow the frontal passage that brings extremely dry air due to a strong westerly or northwesterly flow. Look for strong winds that accompany the flow. Beware of advancing tropical storms as well.

In the ***Southwestern US***, the breakdown of the upper ridge (before monsoons develop) is manifest at the surface with breezy, dry, unstable conditions that transition to potentially very windy conditions as it finally breaks down. During transition to the monsoon pattern, shallow monsoons can produce gusty wind, low RH, and lightning without much precipitation.

In the ***Rocky Mountain and Intermountain Regions***, the most significant pattern is the Upper ridge-Surface thermal trough that produces a dry and windy surface cold front.

- Along the eastern slopes of the Rocky Mountains, weather patterns producing Chinook winds bring strong downslope winds that are unusually dry and warm.
- In the intermountain West, critical fire weather is associated with upper troughs and overhead jet streams, or surface dry cold front passages.



Along the Pacific Coast, from Washington to California, weather patterns producing offshore flow or foehn wind are the most important.

In the Pacific Northwest, the east wind produces strong winds and dry air west of the cascades. The upper ridge breakdown is similar to that described for the Rocky Mountain & interior west.

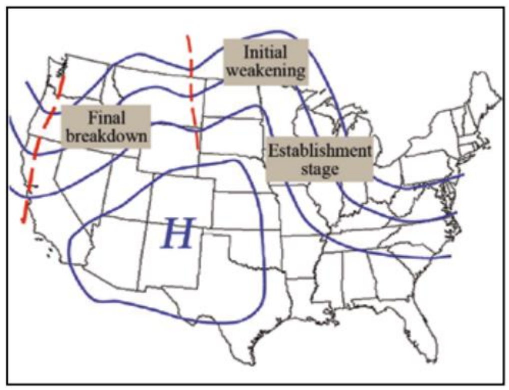
In California, the most important are the north and mono winds of north & central regions and the Santa Ana and sundowner winds of southern California. The subtropical high aloft bring heat waves.

In ***Alaska***, the primary pattern is the breakdown of the upper ridge with a southwest flow. It can bring gusty winds and dry lightning to the interior of Alaska after a period of hot, dry weather.

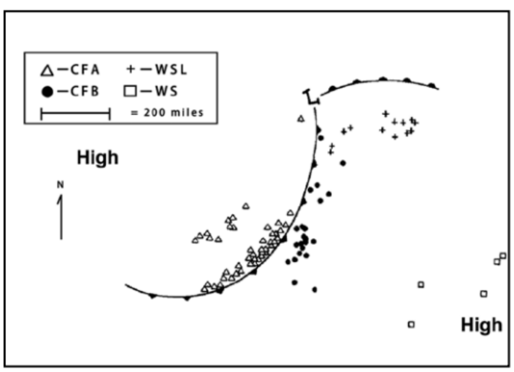
These are key words and catch phrases meteorologists typically use to describe critical fire weather growing and slowing patterns. These terms will often be used to explain weather patterns but are not exclusively used. The terminology will often be found in National Weather Service Area Forecast (AFD) and fire weather planning forecast discussions as well as Predictive Service 7-day outlook assessments.

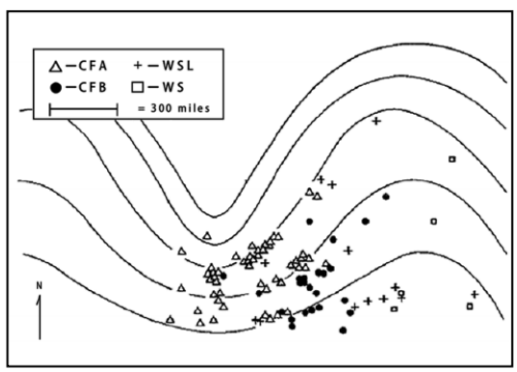
1.3.2 Critical Wind Events

Breakdown of the Upper Ridge and Cold Frontal Passage



Breakdown of the upper ridge involves three main stages. The ***first stage*** represents warmer-drier-breezy and unstable conditions. During the ***second stage***, wind speeds will increase while conditions remain warm-dry and unstable. The ***third stage*** is defined by a cold frontal passage. Significant fire growth across the west and Alaska can be tied to all three stages but occurs most frequently during the second stage. Significant fire growth across the east is primarily related to post-cold frontal conditions or the third stage but can occur during the second stage.

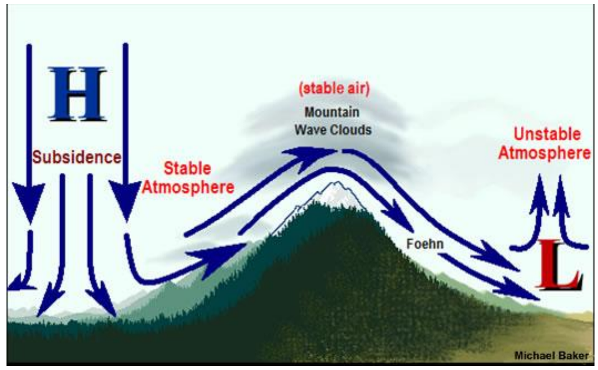




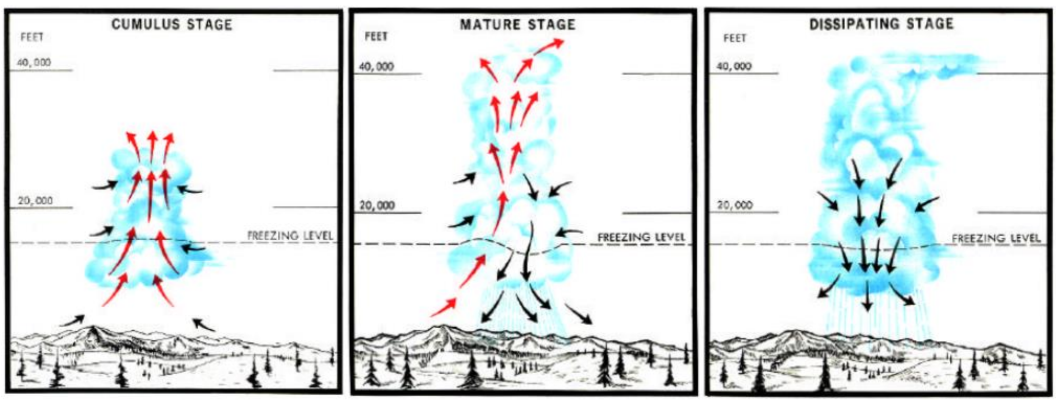
Analysis of locations for fire growth with respect to cold frontal passage and generally breakdown of high pressure ridge. CFA (△) is after the cold front passage, CFB (•) is before cold front passage, WSL (+) is warm sector of low, and WS (□) is warm sector of departing High.

Foehn or Downslope Winds

Foehn or downslope wind events have many regional names. You might recall that foehn, or downslope winds, are caused by air forced over mountain ranges and through mountain passes in association with stable conditions. Common examples are Santa Ana and Chinook winds



Thunderstorm Outflows and Pyrocumulus Downbursts



The mature stage is the most intense period of the thunderstorm. There is extreme turbulence in and below the cloud, with intense gusts superimposed on the updraft and downdraft. Lightning frequency is at its maximum. Heavy rain and strong gusty winds at ground level are typical of most thunderstorms, though precipitation at the ground may be absent in high-level thunderstorms, which we will discuss later. The heaviest rain usually occurs under the center of the cell, shortly after rain first hits the ground, and gradually decreases with time.

Sea Breeze Fronts

Sea breeze or sea breeze fronts can bring gusty, shifting winds and changes in humidity and stability that can drive fire behavior along coastal regions. The few hours leading up to the onset of the sea breeze are the warmest and driest and coincide with increasing wind speeds and unstable conditions. Following the passage of the sea breeze front, conditions will become cooler as well as more humid and stable. Sea breezes are more critical than land breezes because they occur during daylight hours.

Tropical Systems

Tropical systems, including tropical storms and hurricanes, produce an area of relatively warm, dry, and windy conditions around their northern and western periphery as they move ashore.

1.3.3 Hot-Dry-Unstable Events

Critical fire growth periods are also tied to hot-dry and unstable weather patterns. These patterns are generally tied to an ***upper ridge and a strong midlevel dry intrusion***. The upper ridge and dry intrusion are ingredients that oftentimes set-up the Breakdown of the Upper Ridge pattern. A strong heat bubble combined with unusual mixing will create above normal temperatures, sometimes a heat wave, and very low day and nighttime humidity values. The unusual mixing is caused by an unstable atmosphere related to the heat bubble.

Thermal lows can develop near the surface and help concentrate this instability. The hot-dry and unstable weather pattern is typically related to the subtropical or Bermuda high. **Subtropical highs** typically impact the western half of the US and **Bermuda highs** the eastern half. On rare occasions the high's will coalesce and create a super high which can impact large portions of the country.

1.3.4 Fire Slowing or Stopping Patterns

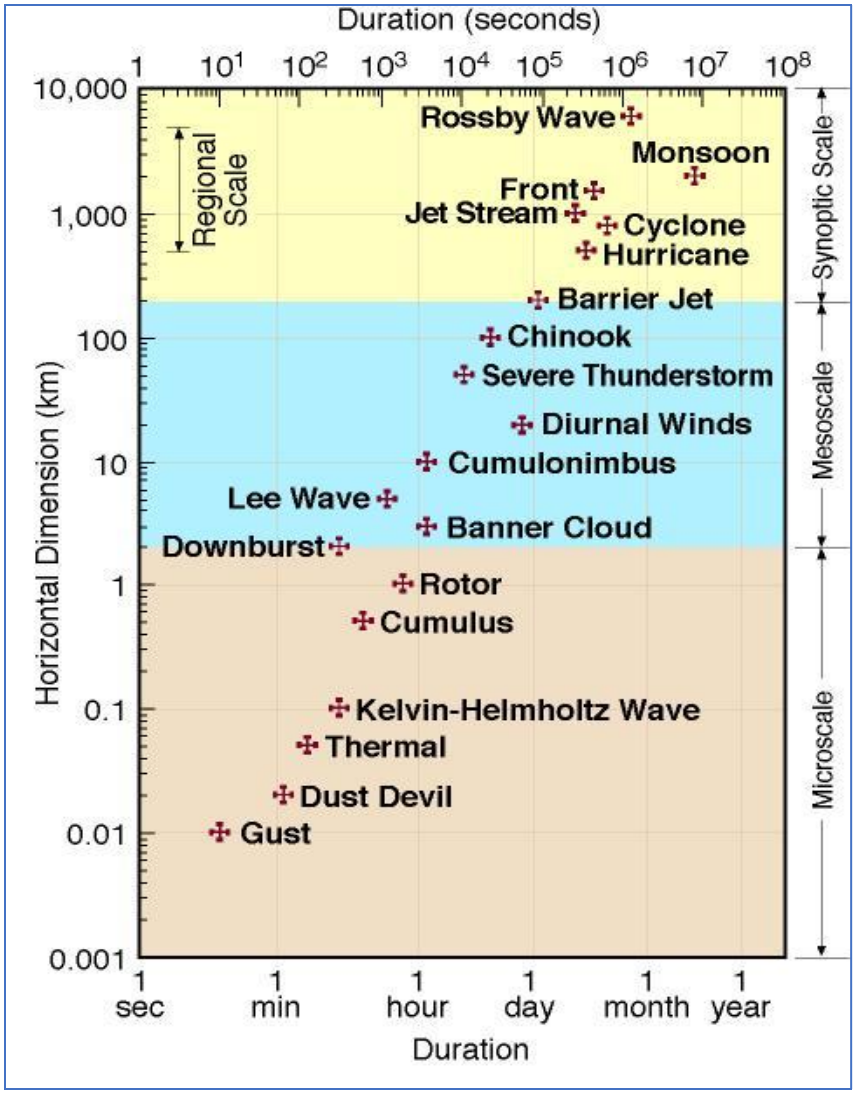
There are three primary reasons why geographical areas experience ***fire-slowing*** and/or ***fire-stopping*** periods; they are related to partial or whole-scale change in the weather and fuel regime. Such change includes partial green-up or fuel moistening promoted by periods of precipitation. Such change also includes temporary changes such as a cool/moist/stable weather regime replacing hot/dry/unstable conditions during a multi-day period. Understand that the fire-slowing and/or fire-stopping period represents a temporary change.

There are four main fire slowing or stopping patterns across the country:

- Closed Low-Deep Trough-Frontal Passages,
- Monsoon Bursts
- tropical storms
- smoke events.

The ***season ending period*** is like the fire slowing period with the main differences being the degree of change in fuels and weather conditions and how long they persist. During the season-ending period, there is an overwhelming change to fuel conditions, such as long-lasting green-up or a significant rise in larger sized fuel moisture values. For most geographical areas, there is not just one event that brings the season's end. It is an **accumulative effect** of a few or several weather events. For example, the Southwest Monsoon develops during a span of several days to weeks and brings about a mosaic change to the live and dead fuels.

1.4 Estimating Winds for Fire Behavior



1.4.1 Definitions

<u>Critical Winds</u>

Critical winds dominate the fire environment and easily override local wind influences. Examples include frontal winds, Foehn winds, thunderstorm winds, whirlwinds, surfacing or low-level jets (reverse wind profiles), and glacier winds.

<u>General (Synoptic Scale) Winds</u>

Synoptic scale, gradient, free air, ridgetop are large scale winds produced by broad scale pressure gradients between high- and low-pressure systems. They may be influenced and modified considerably in the lower atmosphere by terrain and vegetative structure.

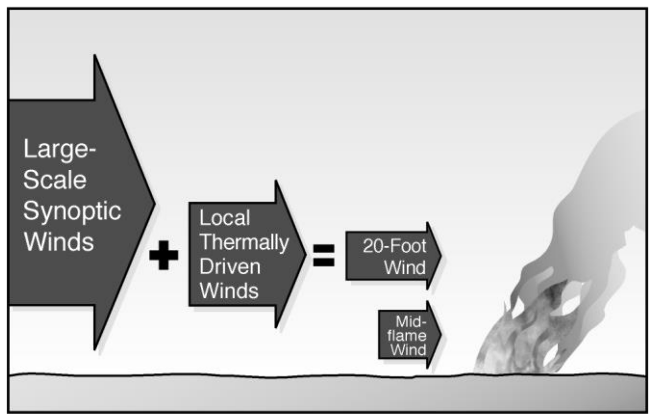
<u>Local (Mesoscale) Winds</u>

(Thermal, convective, drainage) are convective winds caused by local temperature differences generated over a comparatively small area by local terrain and weather. They differ from those which would be appropriate to the general pressure pattern in that they are limited to near surface and are controlled by the strength of the daily solar cycle.

- ***Slope Winds*** are driven by heat exchange at the slope surface. The can react quickly to insolation on the slope, with upslope breezes starting within a few minutes. The strength of upslope winds is also influenced by the length and steepness of the slope as well as the exposure. Upslope winds generally range from 3-8 mph. The transition from upslope to downslope wind begins soon after the first slopes go into afternoon shadow and cooling of the surface begins. In individual draws and on slopes going into shadow, the transition period consists of (1) dying of the upslope wind, (2) a period of relative calm, and then (3) gentle laminar flow downslope. Downslope winds are very **shallow** and of a **slower** speed than upslope winds, [generally 2-5 mph]. The cooled denser air is stable and the downslope flow, therefore, tends to be laminar.
- ***Valley Winds*** are similar to and linked with slope winds. Their development each day generally lags 1-3 hours behind that of slope winds. Peak speeds can be as much as double those of slope winds, reaching 10-15 mph at their peak.
- ***Land and Sea Breeze Circulations***: During the day, Sea/Lake breeze can reach 10-15 mph at the peak of solar heating in the afternoon. The corresponding land breeze is lighter, perhaps 5-10 mph

Surface Winds

Measured near the earth's surface, at an observing station, customarily at some height (usually 20 feet or 10 meters) above the average vegetative surface and a distance equal to at least 10 times the height of any obstruction to minimize the distorting effects of local obstacles and terrain.



Wind Gust Is a sudden, brief increase in speed of the wind. According to U.S. weather observing practice, gusts are reported when the peak wind speed reaches at least 16 knots and the variation in wind speed between the peaks and lulls is at least 9 knots. The duration of a gust is usually less than 20 seconds. NWCG Definition is based solely on the variation between peaks and lulls, at 11.5 mph.

Midflame Windspeed is the estimated windspeed at a height above the surface fuel equivalent to the height at midflame. This is the wind input required for estimating fire spread using the Rothermel surface fire model. It is generally derived from the Surface (20-ft) Wind based on sheltering from an upper canopy or flame height based on fuel bed depth.

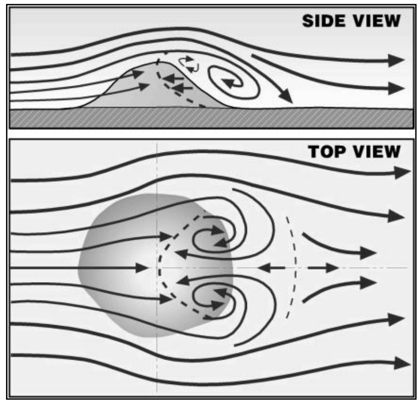
Eye Level Winds are frequently used to represent midflame windspeeds, though that may represent an overestimate for shallow and sparse fuelbeds that have lower flame heights or an underestimate for shrub and crown fuels with deep fuelbeds

Effective Windspeed is the combined effect of Midflame Wind Speed and the slope equivalent windspeed in the direction of maximum spread (head fire). Effective Wind Speed is used to determine the shape (length-to-width ratio) of a point source fire. See section 5.3.

1.4.2 Estimating Surface (20ft) Windspeed in Mountain Terrain

Slopes and Ridges of Mountains

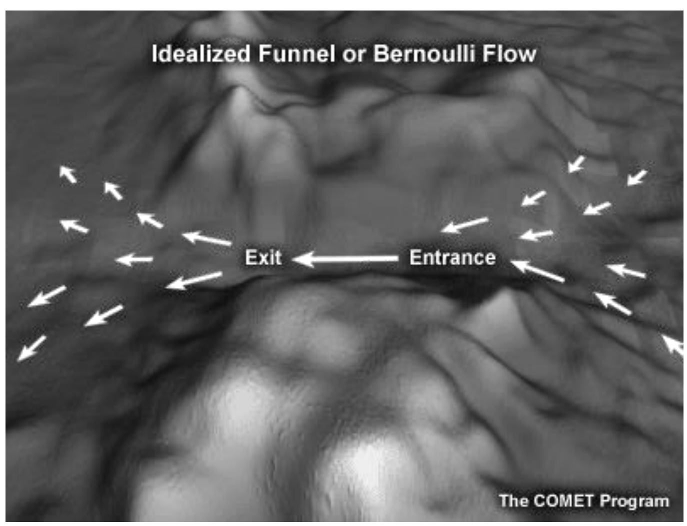
Isolated peaks tend to divert general wind flow horizontally and vertically. Some acceleration of general winds is likely around the flanks and over the top of isolated mountains peaks with gently inclined slopes. On the lee side of the peak, a turbulent reversal (wind eddies) of general wind flow is possible



- Overall, ***mesas*** tend to decelerate general winds because energy must be expended to create local reversals of wind flow called "separation eddies" that form upwind and downwind of steep sided barriers near separation eddies and on top of the mesa, expect 20 ft winds to be decelerated below what might be expected for the general area. Be aware of the potential for frequent gusts and shifts in wind direction near the eddies.

Continuous Ridges: When airmass is instable, general winds tend to ride over the ridge. Under stable conditions, weak winds are blocked and a stagnant zone formed below the ridges. In either case, the atmospheric stability, the strength of the general wind & its angle of incidence, and influence of diurnal winds (which may be opposing) must be considered on the downwind side of the ridge.

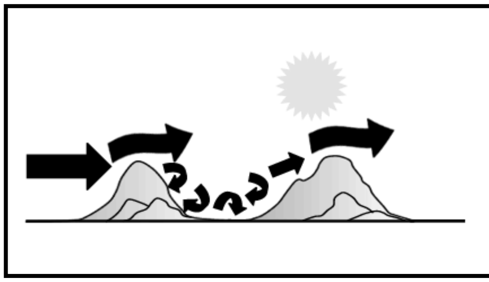
Gaps in Terrain can produce a venturi effect, where winds can be expected to accelerate downwind of the constriction, primarily in the exit region. These gap winds are part of the general wind, because they are based on general winds.

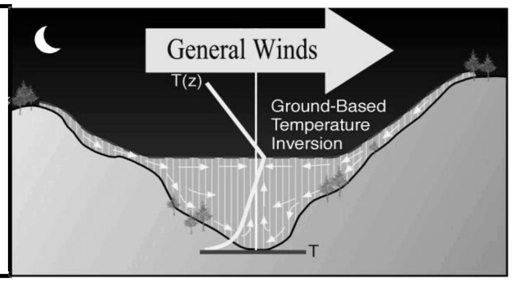


- ***Low Level Gorges*** frequently facilitate gap flow when upwind airmass is stable and discourages the wind from rising over terrain. These gap winds are fairly shallow, less than a few thousand feet
- ***Mountain Passes & Saddles***: upper level winds that impact high terrain tend to flow through the lowest possible spots in a mountain chain rather than climb over it. Local slope and valley winds should be included here.

Valley Influences

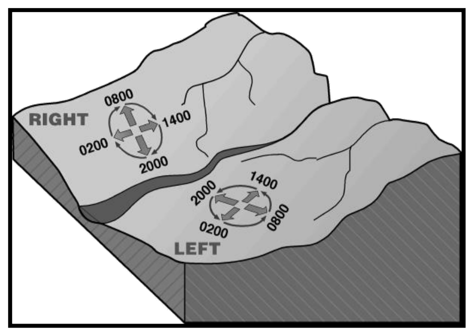
- ***Enclosed or Isolated Basins*** have generally reduced surface wind low on the slopes and valley bottoms. Inversions may limit even the infrequent gusts.

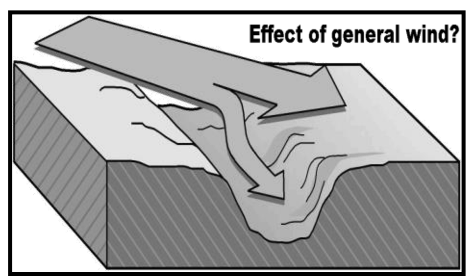




- ***Elongated Valley Winds***

  The Local drainage wind component transitions from upslope as the sun hits the upper slopes, then upvalley as the heating becomes widespread to downslope as the sun sets and down valley during the night





  The general wind influence on surface winds in these valleys depends on its strength, the angle of incidence to the valley axis, the depth of the valley, its aspect alignment, and the time of day.

  ✓ During the day, general winds that are aligned with the upvalley wind will increase the surface winds. Opposing winds will result in decreased surface winds. And perpendicular general winds will contribute little to the local winds found there.

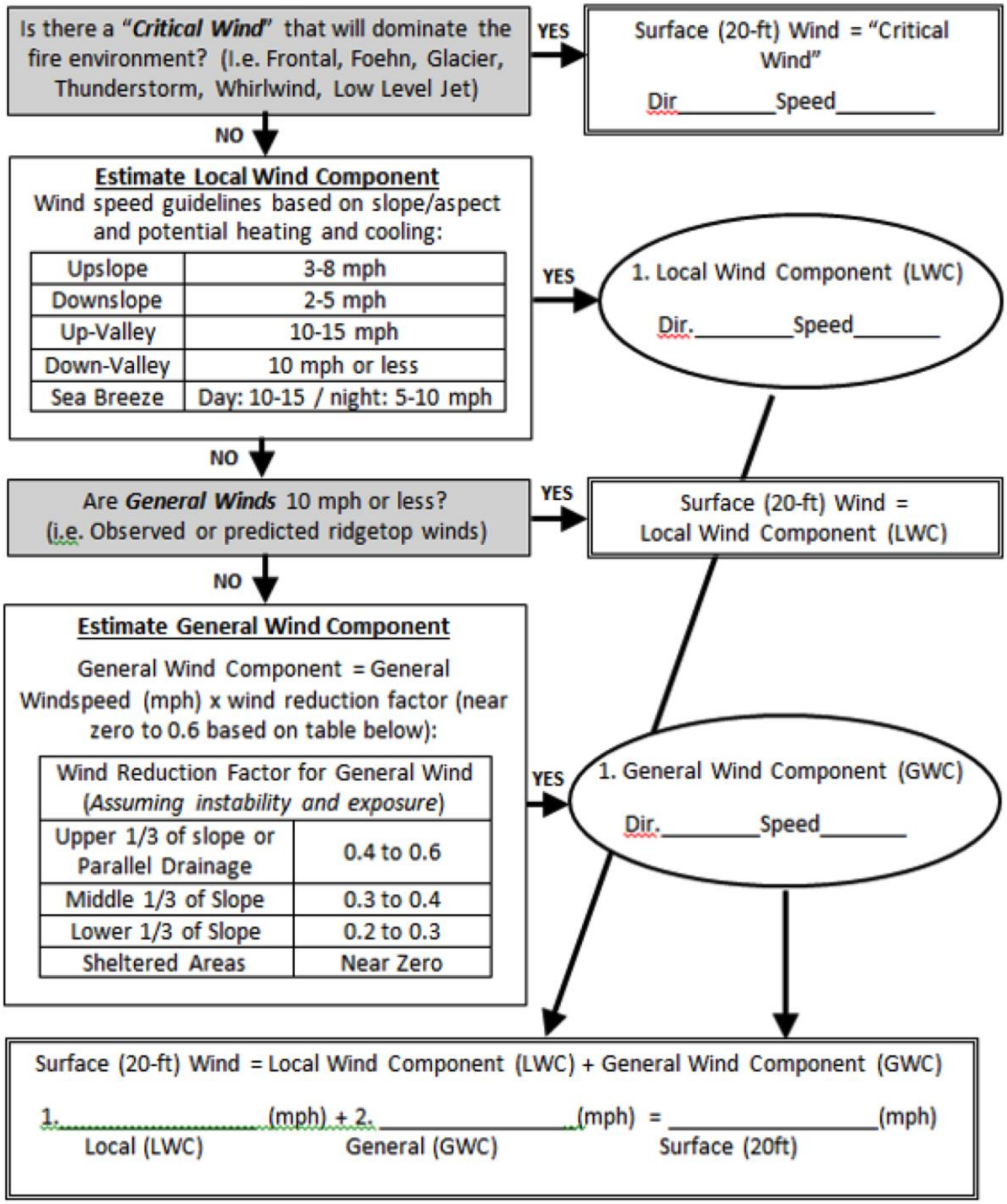
  ✓ During the night, general winds are most likely to surface when they are strong and aligned parallel to the valley axis.

- ***Forked or Bent River Drainages*** are even more dominated by local winds, though the relationships are even more complex. In the daytime, look for general winds to surface primarily in several exposed stretches, creating a mosaic of stronger and weaker surface winds, depending on alignment. At night, the situation is simplified with predominately local downslope and down valley breezes. Beware of strong general winds that are aligned with certain sections.

- ***Inversions in valleys*** are very effective at preventing general winds from surfacing on the midslopes or valley floor. Light local slope and valley flow will likely be the dominant winds. Expect to adjust the 20 ft wind downward when an inversion is present. They generally form at night, but may persist through daylight hours if sunlight is diminished by smoke, fog, or cloud cover. Beware that strong general winds at night can dissipate and inversion through turbulent mixing

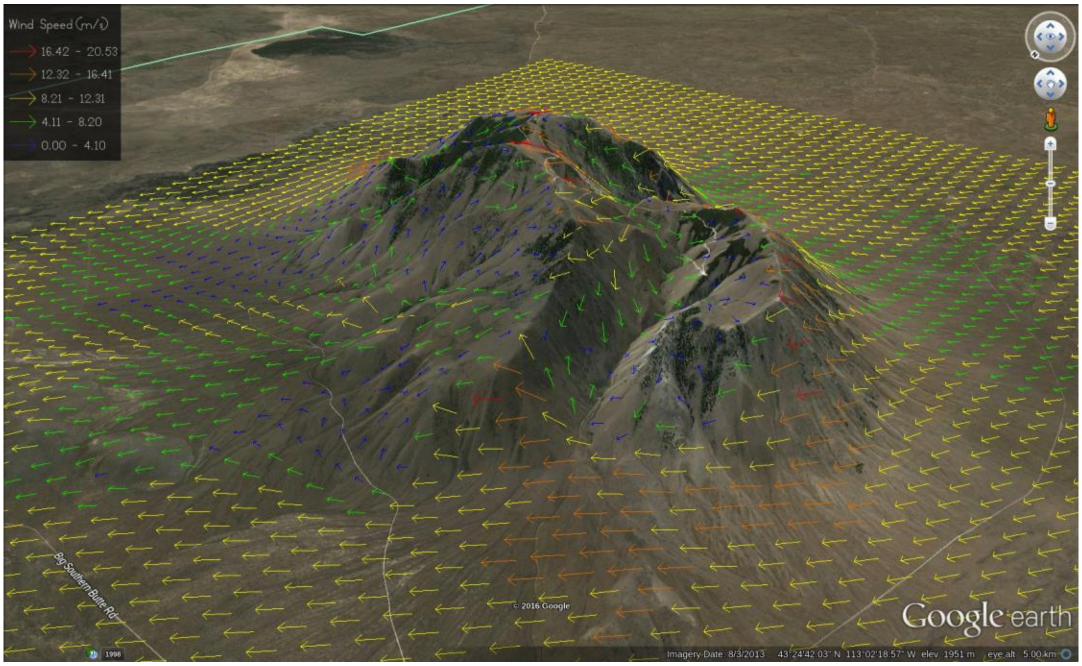
- ***Critical winds*** *(Foehn winds, barrier jets, downslope windstorms, cold air avalanches) may interact locally with the terrain features discussed above and result in even stronger flows.*

1.4.3 Worksheet for Estimating 20-ft Surface Winds



1.4.4 Wind Ninja

WindNinja is a computer program that computes spatially varying wind fields for wildland fire and other applications requiring high resolution wind prediction in complex terrain.



WindNinja can be run in three different modes depending on the application and available inputs.

- The first mode is a forecast, where WindNinja uses coarser resolution mesoscale weather model data from the US National Weather Service to forecast wind at future times.
- The second mode uses one or more surface wind measurements to build a wind field for the area.
- The third mode uses a user-specified average surface wind speed and direction.

Outputs include:

- Direct map display
- Google earth kmz
- ArcGIS shapefiles and asci rasters

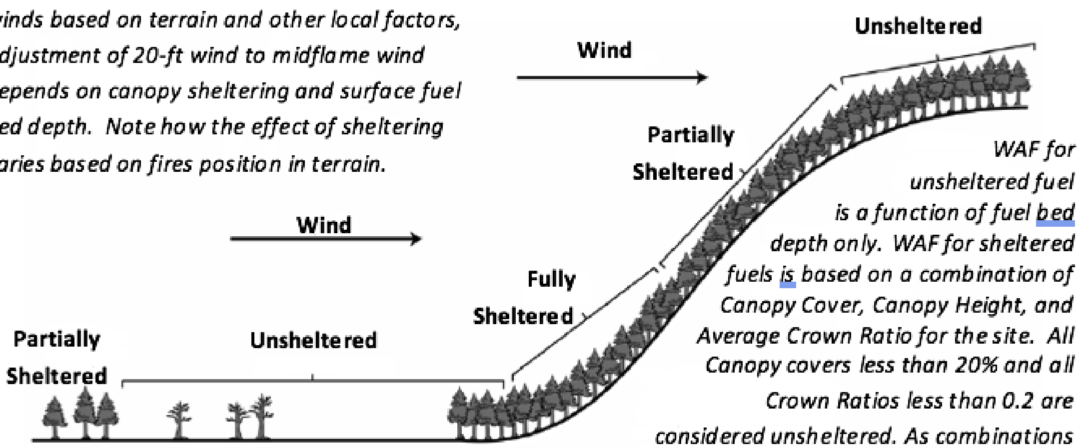
It is available for download to install:

- Windows computers (https://www.firelab.org/document/windninja-software)
- as a mobile App for both Android and IOS mobile devices (http://firelab.github.io/windninja/mobile/)

1.4.5 Adjusting Surface (20ft) Wind to Midflame Windspeed

Sheltering Description	Wind Adj. Factor (WAF)	Fuel Models	Bed Depth	Interpretation
Unsheltered	**0.5**	Grass (gr7, gr8, gr9) Shr (4, sh4, sh5, sh7, sh8, sh9) Slash (13, sb4)	More than 2.7 ft	• Openings on level ground • On high ridges where trees offer little shelter from wind • Leafless canopy • Surface with average Crown Ratio less than 0.2 (crowns less than 20% of tree height) and Canopy Cover less than 20%
	0.4	Grass & Grass-Shrub (1, 2, 3, gr2, gr3,gr4, gr5, gr6, gs1, gs2, gs3, gs4) Shrub (5, 6, 7, sh1, sh2, sh3, sh6) Tbr-Undrsty (10, tu2, tu3) Slash (11, 12, sb1, sb2, sb3	0.9 ft to 2.7 ft	
	0.3	All Timber Litter Fuels (8, 9, tl1 thru tl9) gr1, tu1, tu4, tu5	Less than 0.9 ft	
Partially Sheltered	**0.3**	All Fuel Models	Any	• Patchy Timber • Beneath canopy at midslope or higher with wind blowing directly at slope
Full Sheltered	**0.2**	Open Canopy		• Standing timber on flat or gentle slope • Standing timber near base of mountain with steep slopes
	0.1	Dense Canopy		

Once general winds are adapted to 20-ft surface winds based on terrain and other local factors, adjustment of 20-ft wind to midflame wind depends on canopy sheltering and surface fuel bed depth. Note how the effect of sheltering varies based on fires position in terrain.



WAF for unsheltered fuel is a function of fuel bed depth only. WAF for sheltered fuels is based on a combination of Canopy Cover, Canopy Height, and Average Crown Ratio for the site. All Canopy covers less than 20% and all Crown Ratios less than 0.2 are considered unsheltered. As combinations of these factors increase, WAF becomes partially sheltered, then fully sheltered.

1.5 Atmospheric Stability

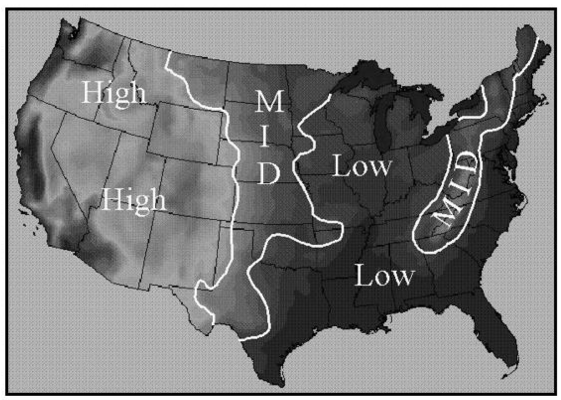
1.5.1 Measures of Stability

Index	Major Factors	Primary Utility	Application
Davis Stability Index	Lapse rate	Basic measure of stability	Southeast US
Ventilation Index	Mixing height and transport wind	Smoke dispersion	
Haines (Lower Atmospheric Stability) Index	Lapse rate and relative humidity	Large fire growth potential	United States
Pasquill Stability Index	Solar radiation, cloud cover and surface wind speed (surface based stability)	Smoke dispersion	SASEM
Lavdas Atmospheric Dispersion Index	Pasquill, mixing height, transport wind	Smoke dispersion and fire growth potential.	Florida

1.5.2 Lower Atmospheric Stability (Haines) Index

The Lower Atmospheric Severity Index, or Haines Index, was developed during the 1980s as a fire weather tool to estimate the effect of atmospheric dryness and stability on the growth potential of a wildfire. The goal was to identify typical combinations of humidity and stability and contrast them with combinations of stability and humidity prevalent during problem fire outbreaks. ***Always reference local Climatology (below).***

Stability Term (A)	Moisture Term (B)
LOW ELEVATION	
950 – 850 mb °C	**950 mb T° C – 950 DP° C**
A = 1 when 3°C or less	B = 1 when 5° C or less
A = 2 when 4-7°C	B = 2 when 6-9° C
A = 3 when 8°C or more	B = 3 when 10° C or more
MID ELEVATION	
850 – 700 mb °C	**850 mb T° C – 850 DP° C**
A = 1 when 5°C or less	B = 1 when 5° C or less
A = 2 when 6-10°C	B = 2 when 6-12° C
A = 3 when 11°C or more	B = 3 when 13° C or more
HIGH ELEVATION	
700 – 500 mb °C	**700 mb T° C – 700 DP° C**
A = 1 when 17°C or less	B = 1 when 14° C or less
A = 2 when 18-21°C	B = 2 when 15-20° C
A = 3 when 22°C or more	B = 3 when 21° C or more



Haines Index (A + B)	Potential for Large Fire
2 or 3	Very Low
4	Low
5	Moderate
6	High

Haines Index Climatology

40 Year (1961-2000) Climatology of Haines Index for North America, https://www.fs.fed.us/pnw/airfire/haines/index.html

NWS Western Regional Tech Attachment NO.97-17, https://www.weather.gov/media/wrh/online_publications/TAs/ta9717.pdf

1.6 Fire Season Climatology

1.6.1 Drought Assessments

Meteorological Indicators

A wide range of weather based indices are available, based on accumulated precipitation alone, as well as precipitation combined with modeled evaporation and/or transpiration rates. These include spatial representations of soil moisture, vegetative stress, agriculture, and water supply. Many can be found using the ***assessment resources*** listed below.

Standardized Precipitation Index (SPI) is the number of standard deviations that the observed value would deviate from the long-term mean. Since precipitation is not normally distributed, a transformation is first applied so that the transformed precipitation values follow a normal distribution. http://www.wrcc.dri.edu/spi/spi.html

Quantitative Precipitation Estimate (QPE) show spatial distribution of precipitation are multi-model estimates. Using a multi-sensor approach, it is one of the best sources of timely, high resolution precipitation information available. (http://water.weather.gov/precip/about.php)

National Fire Danger Rating System (NFDRS) includes the 1000-hr time lag fuel moisture, Energy Release Component (ERC), Growing Season Index (GSI), and Keetch-Byram Drought Index (KBDI) among its outputs. *See Fire Danger Section.*

Canadian Forest Fire Danger Rating System (CFFDRS) includes the Duff Moisture Code (DMC), Drought Code (DC), and Buildup Index (BUI) among its codes and indices. *See CFFDRS Section*.

Assessments Resources

The ***US Global Climate Change Research Program (USGCRP)*** is mandated by Congress in the Global Change Research Act (GCRA) of 1990 to "assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change." (http://www.globalchange.gov/)

NOAA Climate.gov is a source of timely and authoritative scientific data and information about climate. It provides news items, maps and data, and teaching resources. (https://www.climate.gov/)

Western Water Assessment; NOAA Integrated Sciences & Assessments (http://wwa.colorado.edu/climate/dashboard2.html)

Drought Monitor; National Drought Mitigation Center (http://droughtmonitor.unl.edu/)

National Integrated Drought Information System; Nat. Centers for Environmental Information (https://www.drought.gov/drought/)

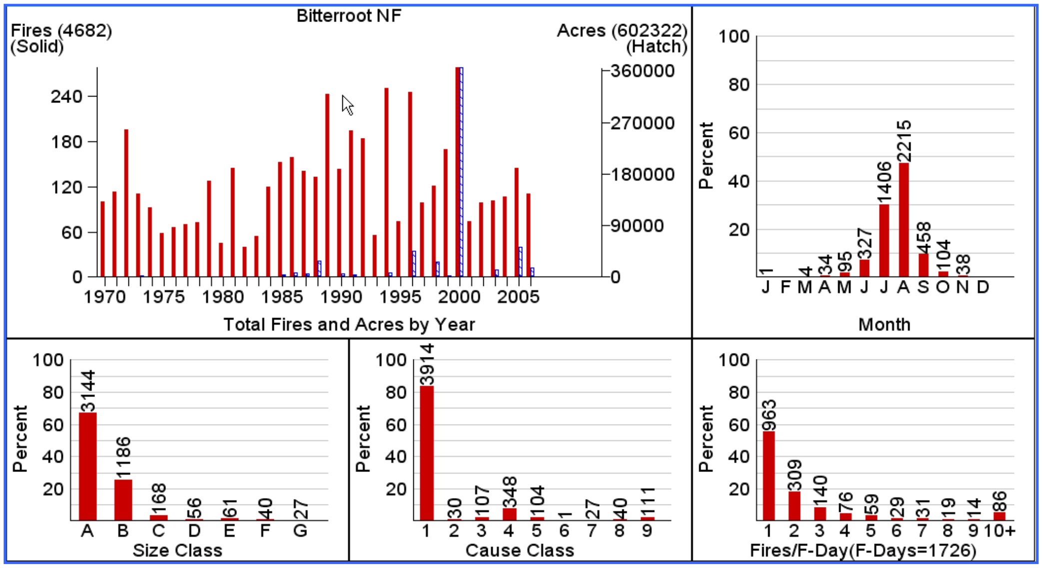
National Drought Mitigation Center; University of Nebraska – Lincoln (http://drought.unl.edu/MonitoringTools.aspx)

River Forecast Centers; NWS Advanced Hydrological Prediction Services provides depictions of river flows and flooding; rain and snow fall in graphic and digital formats (https://water.weather.gov/ahps/rfc/rfc.php)

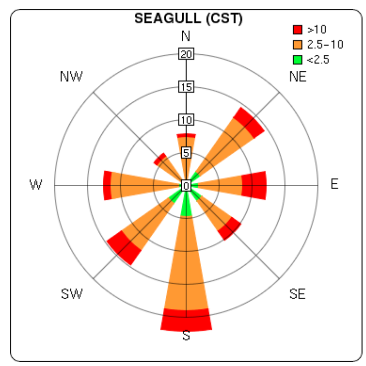
1.6.2 Local Climatology and Current Season Trends

Evaluate Fire Occurrence Patterns

Firefamily Plus depictions of fire occurrence patterns are good for evaluating ignition patterns, but may provide little insight to climatology and fire growth.



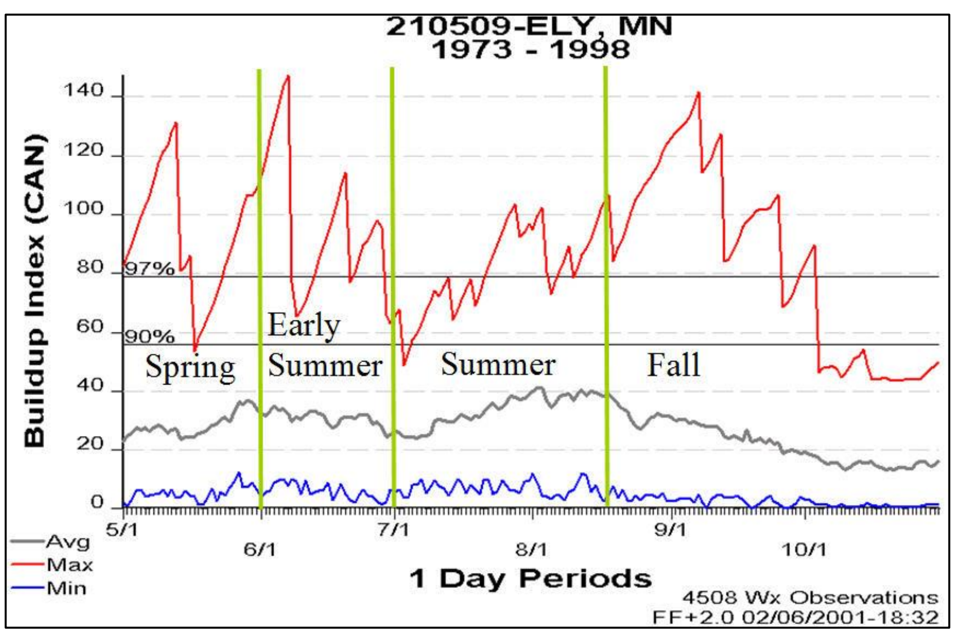
Identify Normal Seasonal Trends



Local Winds Climatology

Wind roses are available in Firefamily Plus, wrcc.dri.edu, and in other tools. Insure it includes only relevant winds (for example – exclude other seasons, night time winds, etc.)

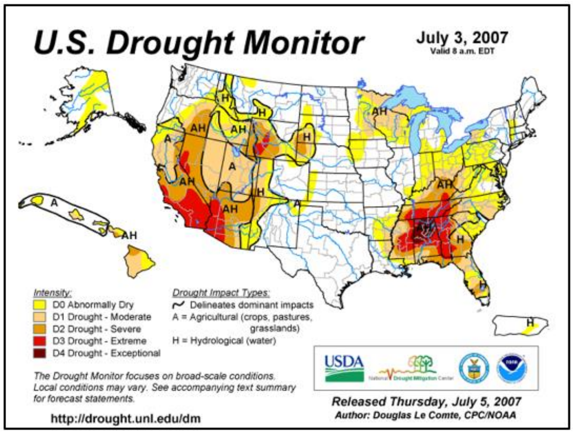
Use Appropriate ***Fire Potential Indicators*** (ERC, BUI) and determine season start, peak season, shoulder seasons, and season end.

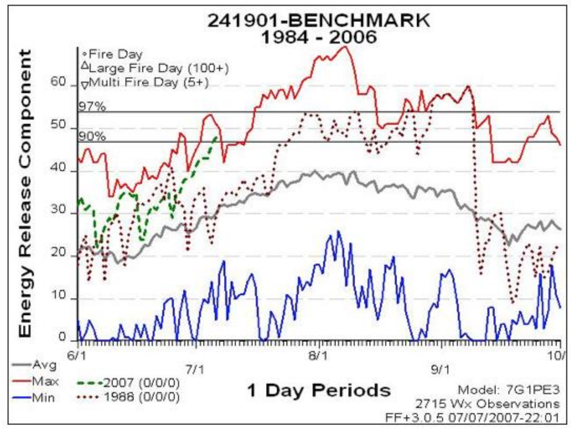


Current Trends and Historic Norms/Extremes

General Trends

Evaluate and depict current conditions spatially, using a combination of drought assessment resources appropriate for the area of interest.





Current Local Conditions

Graphical Time Series depictions can highlight seasonal departures from norms and exceptional events. This Firefamily Plus Climatology graphic includes historic range (average, max, min), current year, and analog year.

Consult with Local Managers and Experts

Get their help evaluating the objective analysis and to identify any local anomalies that may not be apparent.

Evaluate historic trends for weather that slows or stops fire growth

Fire Stopping Events:

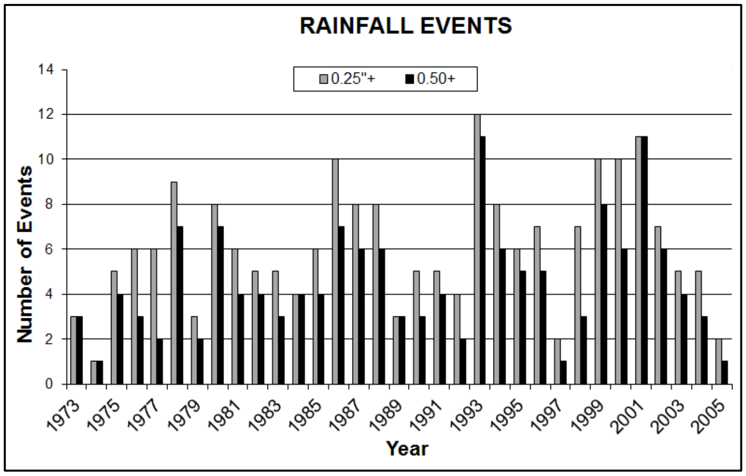
Originally reported by Latham and Rothermel (1993) from opinions of persons familiar with fire and fire weather in the Northern Rockies, example criteria were suggested as 0.5 inches of rain accumulated in 5 days or less. However, other fire potential indicators, such as cloud cover and relative humidity, can help identify periods of continuous low- or no-spread days during a fire season in a locality. These discrete events may not signal the end of the fire or the season. As such, it may be just as important to identify the frequency with which they occur and the duration of their influence as it is to predict a waiting time for the next event.

Fire/Season Ending Date

It is possible to identify the date in a fire season when fire growth is no longer likely or possible. This is generally understood to be the season end. If a fire's threat to values of concern is more imminent or it is early in the fire season, a prediction of the season end may be less important than suggesting if and when a weather event will put the fire out. In bimodal seasons, such as the spring seasons in the southwest and the lake states, weather criteria can suggest fire ending dates in the early "season", even though fire potential is expected to rise again in subsequent periods. Anticipating this date may be critical to strategic decisions as the season end approaches.

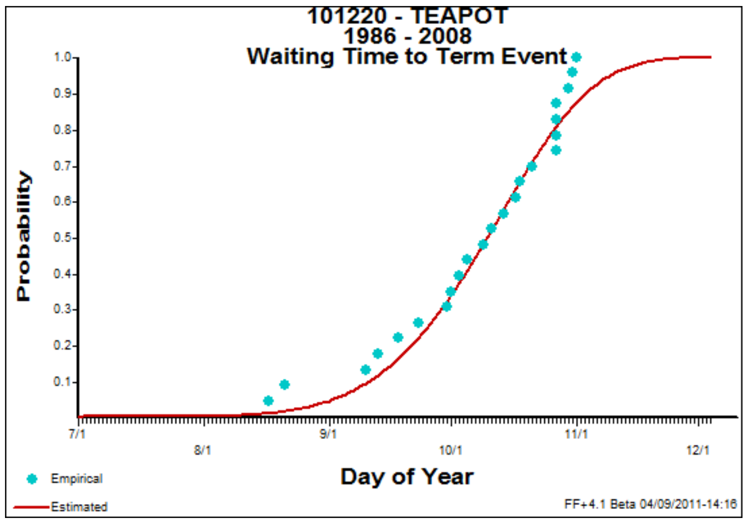
Event Frequency and Duration

As suggested above and depicted here, it may be valuable to identify the frequency of fire slowing or stopping events, especially if they are more common, such as in the eastern US. Firefamily Plus Event Locator can be used to evaluate data from a local RAWS station.



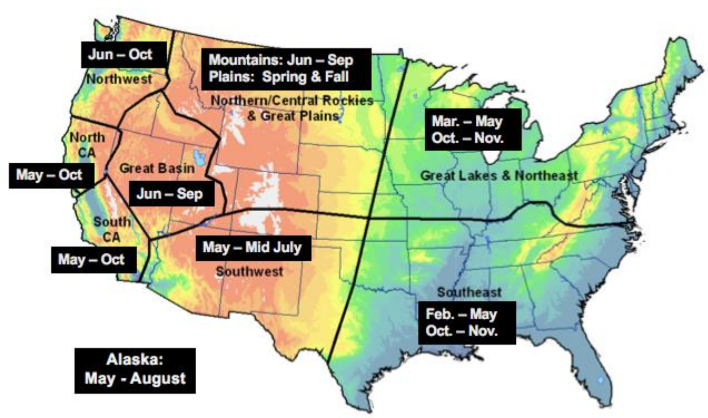
TERM Waiting Time Distribution

Firefamily Plus (version 4.1) includes a "TERM" tool (in the Weather menu) to produce a waiting time distribution of historic fire- or season-ending dates. For each year evaluated, a single date is selected as the ending date based on established criteria. These dates are recorded and the distribution plotted to estimate the probability that the fire or season will end by a specific date.



1.6.3 Regional Fire Seasonality (Fire Occurrence by Month)

The basic climate/weather factors temperature (hot vs. cold), atmospheric moisture (dry vs. moist), and wind patterns affect the fuel conditions and the tendency for fire start and spread. Fire season characteristics are driven by seasonal and continental-scale weather patterns, their movement, and variation. **Seasonal** air mass and jet stream changes affect various regions at different times and in different ways.



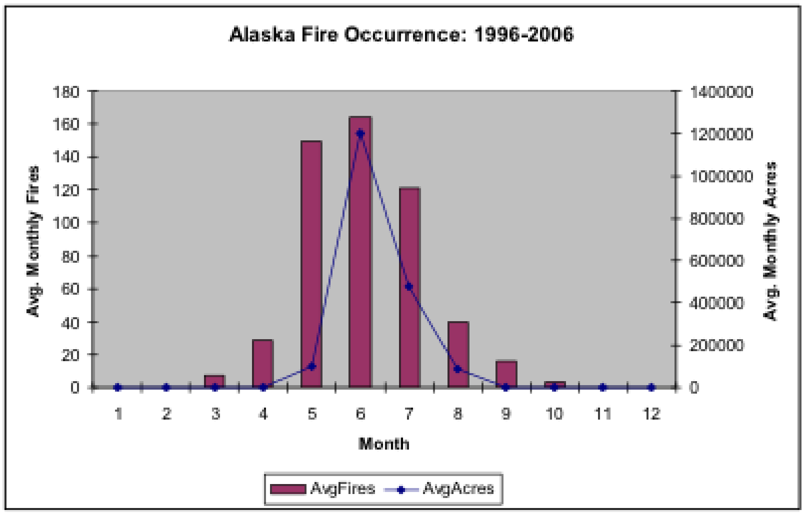
The following will be key words and catch phrases meteorologists typically use to describe critical fire weather growing and slowing patterns. These terms will often be used to explain these weather patterns but not exclusively used. The terminology will often be found in National Weather Service Area Forecast (AFD) and fire weather planning forecast discussions as well as Predictive Service 7-day outlook assessments.

Alaska

Climatology

- Winter – Generally very cold and dry.
- Spring – Cold and dry early, then warming with increasing downslope wind event potential
- Summer – Warm & dry with lightning in June, then gradually moistening. Occasional wind events.
- Fall – Moist initially, then back towards winter conditions.

Fire Activity



- Peak fire activity late spring & summer coincident with warmest/driest conditions, and wind event & dry lightning potential
- Great majority of activity in interior between Alaska and Brooks ranges
- Season ramps up quickly after melt-off and strongly relates to length of day
- Season ends quickly with late summer/early fall moisture increase

Critical Weather Events

Foehn and Downslope wind

Glacial Katabatic downstream from glaciers (e.g. Juneau fjords), Alaska Range Chinook in the western Tanana Valley, "Hillside" Katabatic Winds (e.g. Anchorage Bowl), and Yukon "Chinook" winds in the eastern interior and through the Brooks Range.

Breakdown of the Upper Ridge

Boreal interior area from Galena to Fort Yukon, warming-drying ahead of the Low-Pressure System originating from the Sea of Okhotsk with gusty W-SW winds, and Low Pressure moving inland and loses wetting characteristics but keeps enough moisture for drier storms.

Fire Slowing or Stopping Events

Closed Low/Occluded Low is a Low-Pressure system that originate from the Sea of Okhotsk and Bering Sea moves inland and stays for a multi-day period or a persistent moist southwest flow impacting the coastal areas.

Marine Inversion: Coastal areas of Alaska especially during night.

Fire Growth Potential Indicators

FFMC and BUI, ISI and FWI

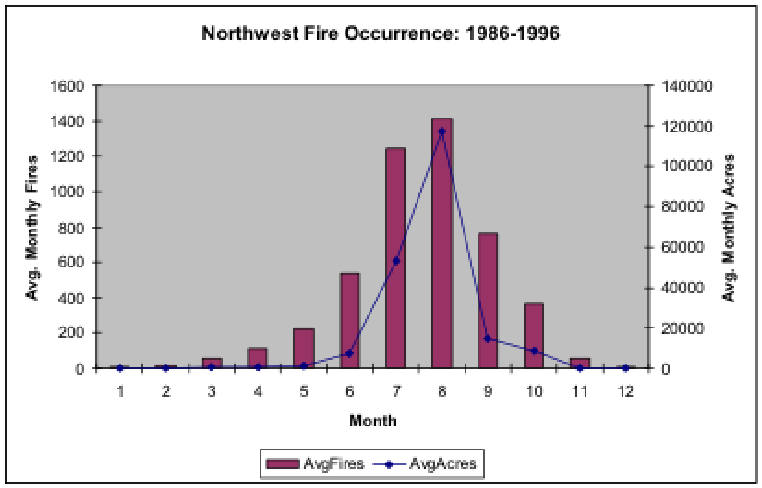
Northwest

Climatology

- Winter/Spring – Cool & moist with frequent & abundant precipitation, especially western portion of area. Relatively dry east.
- Summer – Some windy & dry potential early, then becoming generally warm & dry with infrequent wind events due to dry cold fronts.
- Fall – Return of cooler, more moist conditions ushered in by a period of windy, dry conditions with cold frontal passages. Potential for dry offshore wind events behind storm systems.

Fire Activity

- Fire activity peaks in summer due to increasingly warm & dry conditions and potential for wind and lightning with dry cold frontal passages.
- Rapid decrease in activity in fall with Pacific moisture on the increase, though this the peak period for dry offshore wind events and a few dry cold front passages are still possible.



- Little to no activity late fall through spring.

Critical Weather Events

- Thermal Low/Subtropical Ridge,
- Breakdown of the Upper Ridge and Passage of a dry cold front, and
- Foehn or Downslope Wind (East Wind west slopes of Cascades and Chinook Wind east slopes of the Cascades)

Fire Slowing or Stopping Events

- Closed Lows/Wet Cold Front
- Marine Layer/Onshore flow
- Smoke Events

Fire Growth Potential Indicators

- Energy Release Component
- 100 hr fuel moisture
- AVHRR satellite NDVI DA and RG
- NWS QPE (30-60 days)
- Drought Monitor

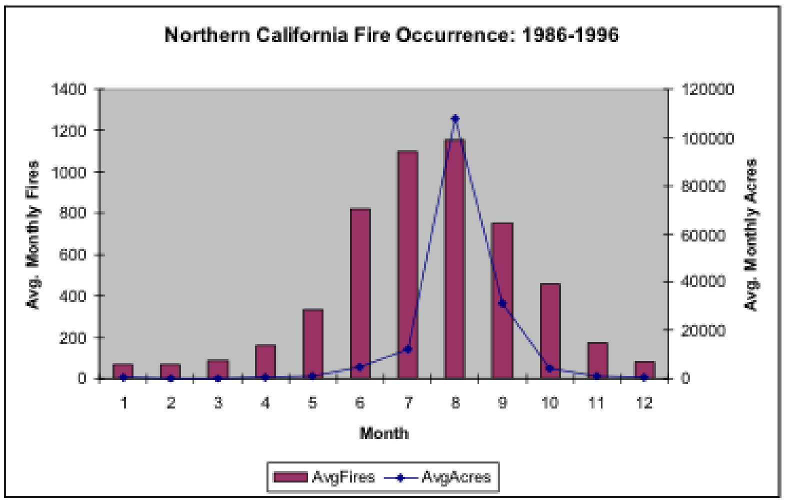
Northern California

Climatology

- Winter/Early Spring – Cool and moist with regular precipitation events, especially in the mountains.
- Late Spring/Summer – Some windy/dry potential early, then generally warm & dry with infrequent wind events due to dry cold front influences.
- Fall – Return of cooler, more moist conditions ushered in by a period of windy, dry conditions with cold frontal passages. Potential for dry, north through east wind events behind storm systems.

Fire Activity

- Fire activity peaks in summer due to increasingly warm & dry conditions and potential for wind and lightning with infrequent dry cold frontal passages.
- Rapid decrease in activity by late fall with Pacific moisture on the increase, though peak period for dry northeast wind events.



- Little to no activity late fall through early spring.

Critical Weather Events

- Foehn or Downslope wind (Mono, North winds)
- Breakdown of the Upper Ridge in the Interior
- Subtropical Ridge/Thermal low

Fire Slowing or Stopping Events

- Closed Low/Pacific Trough
- Marine Layer/Onshore flow
- Smoke Events

Fire Growth Potential Indicators

- Spread Component (SC)
- Burning Index (BI)
- Energy Release Component (ERC)
- Live Fuel Index (LFI)/Growing Season Index (GSI)
- AVHRR satellite NDVI DA and RG
- NASA SPoRT GVF
- NWS QPE (30-60 days)
- Drought Monitor

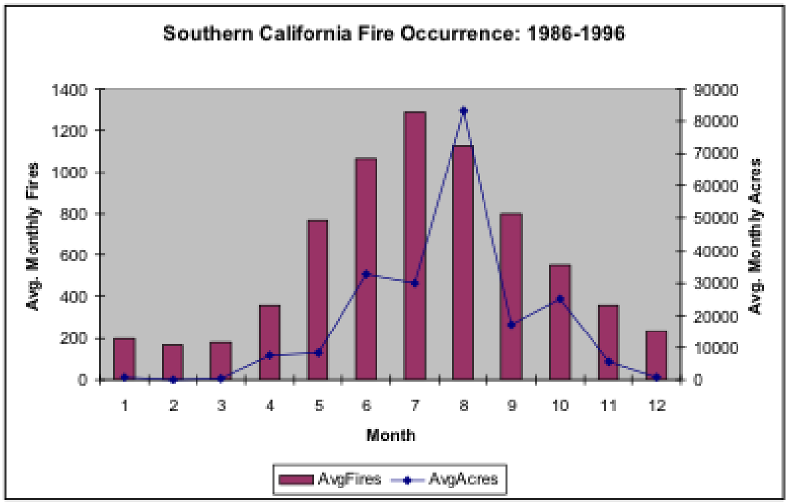
Southern California

Climatology

- Winter – Occasional storm systems with mainly mountain precipitation. Inland intrusions of cool, moist Pacific air. Relatively dry inland lower elevations.
- Spring – Less frequent precipitation events and substantial inland intrusions of marine air.
- Summer - Hot & dry inland and maritime influence along coast. Occasional influx of monsoon moisture from southeast.
- Fall – End of any monsoon moisture influence and begin of gradual inland shift in marine air mass. Period of greatest potential for dry offshore wind events.

Fire Activity

- Fire activity peaks late spring through fall, when influence of maritime air is diminished.
- Greatest potential for offshore wind events in the fall, when fuels are often driest.
- Little activity winter-early spring due to maritime influence.
- Fires possible at any time with offshore wind events.



Critical Weather Events

- Foehn or Downslope wind (Santa Ana and Sundowners)
- Breakdown of the Upper Ridge away from the coasts
- Subtropical Ridge

Fire Slowing or Stopping Events

- Marine Layer/Onshore flow
- Closed Low/Pacific Trough

Fire Growth Potential Indicators

- Spread Component (SC)
- Burning Index (BI)
- Energy Release Component (ERC)
- National Fuel Moisture Database
- Live Fuel Index (LFI)/Growing Season Index (GSI)
- AVHRR satellite NDVI DA and RG
- NASA SPoRT GVF
- NWS QPE (30-60 days)
- Drought Monitor

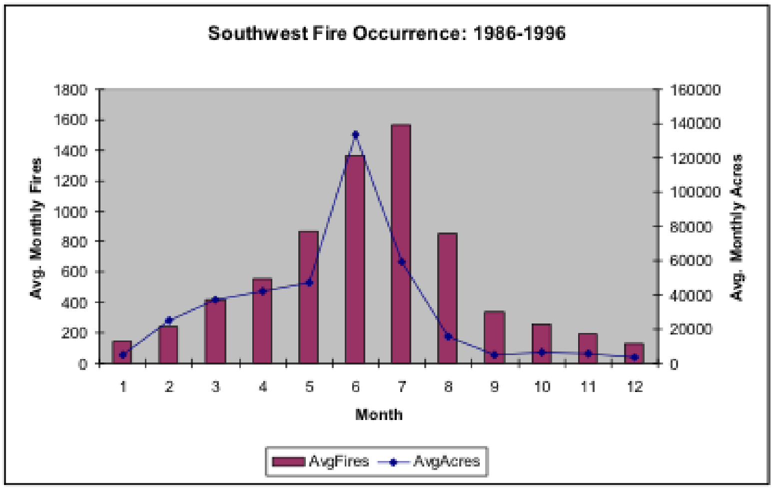
Southwest

Climatology

- <u>Winter</u> – Cool to cold with occasional precipitation. Dry downslope winds possible in lee of Rockies.
- <u>Spring</u> – Warming, windy & dry transitioning to hot & dry.
- <u>Summer</u> – Hot & dry gives way to warm & moist abruptly with monsoon.
- <u>Fall</u> – Turning much drier & mild. Potential for few wind events followed by dropping temperatures.

Fire Activity

- Fire activity increases in spring as it transitions from windy & dry to hot & dry
- Peak from May – mid-July, with monsoon thereafter
- Rare secondary fall season as moisture exits and jet drops south & wind event potential returns
- Little activity late fall - early winter



Critical Weather Events

- Breakdown of the Upper Ridge
- Subtropical Ridge
- Monsoon transition (Edge of a Monsoon Burst and Edge of Back Door Cold Front)
- Foehn or Downslope wind
- Low Level Jet on rangeland of the Front Range
- Surface Dryline Passage on rangeland of the Front Range

Fire Slowing or Stopping Events

- Closed Low-cold frontal passage
- Back Door Cold Front
- Monsoon Burst

Fire Growth Potential Indicators

- ERC and BI
- NFMD
- LFI/GSI
- AVHRR satellite NDVI RG and DA
- NASA SPoRT GVF
- NASA SPoRT RSM (0 to 10 cm)
- NWS QPE (30 day)
- Drought Monitor

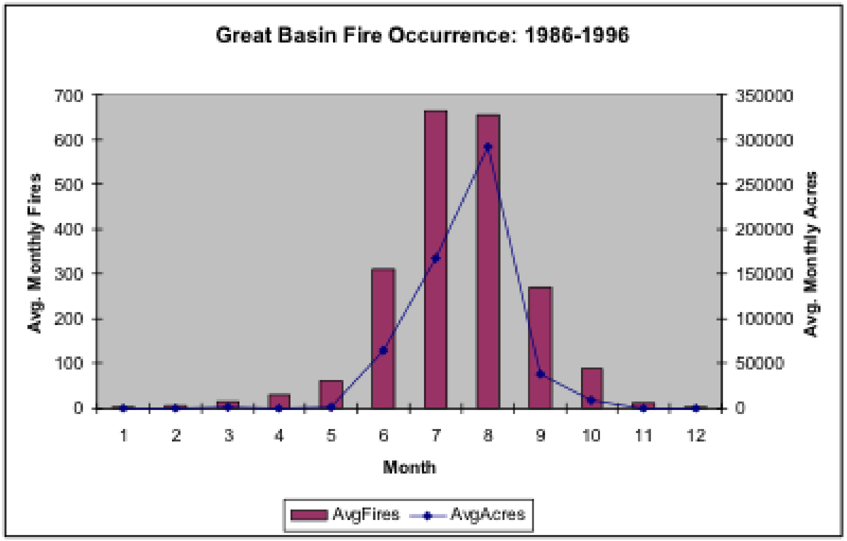
Great Basin

Climatology

- Winter – Periodic precipitation, mainly over mountains.
- Spring – Becoming windy, dry, and warmer.
- Summer – Hot & dry. Periodic wind events north and moisture surges south.
- Fall – Period of windy & dry conditions often followed by period of fair & dry weather before cooler temperatures and increased precipitation potential.

Fire Activity

- With generally fine fuel types, fire season dependent on cured fuels and windy/dry conditions
- These conditions occur almost exclusively in the summer.
- Little to no activity outside of summer.



Critical Weather Events

- Breakdown of the Upper Ridge
- Subtropical Ridge
- Edge of a Monsoon Burst (Hybrid)
- Foehn or Downslope wind (Chinooks down east slopes of the Sierras and west slopes of the Wasatch Mountains)

Fire Slowing or Stopping Events

- Closed Low/Pacific trough
- Monsoon Burst, duration of 3 days or more

Fire Growth Potential Indicators

- ERC and BI
- National Fuel Moisture Database
- LFI/GSI
- AVHRR satellite NDVI DA and RG
- NWS QPE (30-60 days)
- NASA SPoRT RSM 0-10 cm/GVF
- Drought Monitor

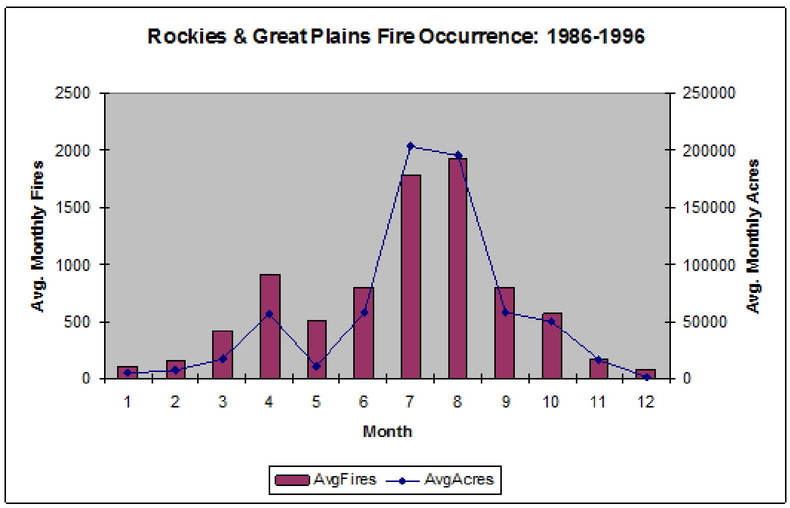
Northern/Central Rockies & Great Plains

Climatology

- Winter – Regular storm systems and precipitation, especially over mountains. Cold overall with potential for artic air intrusions.
- Spring – Period of heaviest precipitation in the mountains, but greatest Chinook wind potential in lee of Rockies and adjacent plains.
- Summer – Warm and dry over most mountain areas with occasional wind events north. Increasingly moist across the plains and far south.
- Fall – Period of windy/dry potential, then fairly dry and mild until temperatures drop & moisture increases.

Fire Activity

- Fire activity on the plains peaks in spring and fall when windy/dry periods are coincident with dormant or cured fine fuels.
- Fire activity in the mountains peaks in the summer, when it's warmest and driest and some dry cold frontal passages are possible.
- Little to no activity late fall through early spring.



Critical Weather Events

- Breakdown of the Upper Ridge (Dynamic dry slot and Dry Cold Front)
- Subtropical Ridge (Mid-level dry intrusion)
- Edge of a Monsoon Burst (Hybrid)
- Foehn or Downslope wind (Chinook)
- Low Level Jet and Surface dryline on the Great Plains

Fire Slowing or Stopping Events

- Closed Low-Pacific Trough-cold frontal passage
- Monsoon Burst
- Smoke Event

Fire Growth Potential Indicators

- ERC and BI
- National Fuel Moisture Database
- Live Fuel Index (LFI)/Growing Season Index (GSI)
- AVHRR satellite NDVI DA and RG
- NASA SPoRT GVF
- NWS QPE (30-60 days)
- Drought Monitor

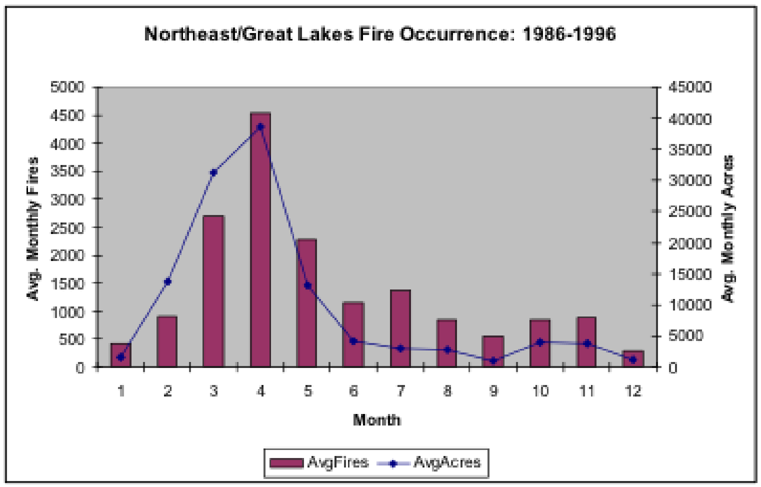
Great Lakes & Northeast

Climatology

- Winter – Generally cold with dry periods between widespread periodic precipitation.
- Spring – Warmer, windier, and drier. Driest immediately behind storm systems.
- Summer – Generally warm & humid under Bermuda High influence. Occasional windy/dry events far north.
- Fall – Turning much drier, then generally mild & dry with potential for windy & dry periods before temperatures drop.

Fire Activity

- Fire activity maxima in spring and fall, coincident with windy periods near jet stream
- Building warmth and dormant fine fuels in spring, leaf-off in fall
- Season can extend well into summer far north if jet remains active and brings windy/dry events that are preceded by dry conditions of 2 weeks or more.



- Little or no activity winter months

Critical Weather Events

- Post Cold frontal
- Pre-Cold Frontal Southwest Wind cases
- Bermuda High

Fire Slowing or Stopping Events

- Cold frontal passage
- Stationary front
- Closed Low

Fire Growth Potential Indicators

Canadian Forest Fire Danger Rating System

- Build-Up Index (BUI)
- Fire Weather Index (FWI)
- Initial Spread Index (ISI)

National Fire Danger Rating System

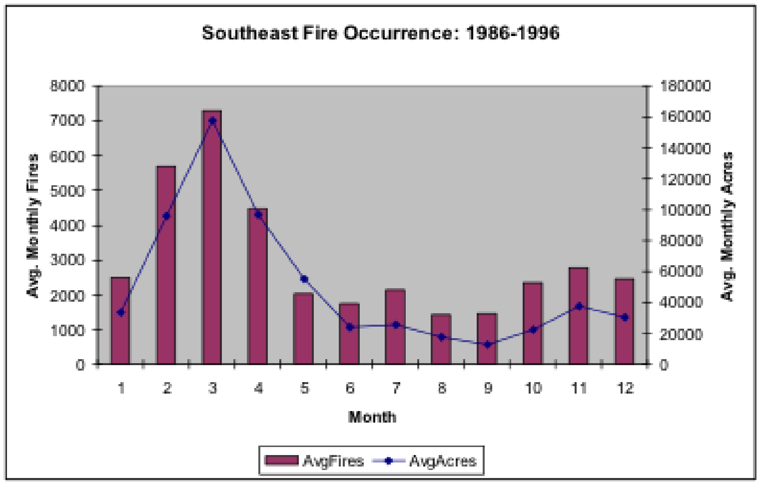
- Ignition Component (IC)
- Spread Component (SC)
- Energy Release Component (ERC)
- AVHRR NDVI RG and DA

Southeast

Climatology

- Winter – Generally driest time of year with greatest wind event potential behind passing storms, though widespread precipitation can also occur.
- Spring – Windy/dry potential retreats north, and warm, moist conditions become increasingly dominant.
- Summer – Warm to hot & humid with light winds. Occasional dry spells. Tropical cyclone activity increases late in the season.
- Fall – Very moist initially, then gradual infiltration of dry air. Moist conditions often persist along Gulf Coast.

Fire Activity



- Fire activity maxima in late winter / early spring and fall, coincident with greatest potential for windy/dry conditions behind passing storm systems
- Dormant fine fuels with low live fuel moisture in winter & spring, leaf-off in fall in northern portion of region
- Season can extend year-round anytime warm/moist air becomes suppressed south & east
- Usually little activity summer months, though significant fire activity has historically occurred during unusual dry spells

Critical Weather Events

- Post Cold frontal
- Westerly Downslope wind in the Appalachians and Ozarks
- Sea Breeze
- Tropical Storms
- Bermuda High

Fire Slowing or Stopping Events

- Closed Low/cold frontal passage
- Stationary Front
- Tropical Storm
- Sea Breeze

Fire Growth Potential Indicators

- ERC
- 100 hr Fuel Moisture
- Keetch-Byram Drought Index (KBDI) is sometimes misused
- Standardized Precipitation Index (SPI)
- Crop Moisture Stress Index
- NWS QPE (30 to 60 day)

1.7 Fire and Weather Data

1.7.1 Sources of Digital Weather and Fire Records

FAMWEB Fire & Weather Data

(https://fam.nwcg.gov/fam-web/weatherfirecd/state_data.htm) provides access to all archived daily fire weather records for NFDRS stations in the United States, both manual and automated. It also is the source of fire occurrence data for all federal agencies and some state agencies. These files are formatted for easy import into Firefamily Plus. Updated annually.

Kansas City Fire Access Software (KCFast)

(https://fam.nwcg.gov/fam-web/kcfast/mnmenu.htm) provides user requested access to archived and current weather records from NFDRS stations in the United States. Hourly records are stored for the most recent years and all daily records archived in the Weather Information Management System (WIMS) are available. Fire occurrence records are available as well. File formats are compatible with Firefamily Plus import. ***Updated daily.***

Western Region Climate Center

(http://www.wrcc.dri.edu/wraws/) provides an archive to all Satellite (GOES) enabled RAWS stations. It is the most complete archive of hourly observations for the RAWS network. The interface provides many display alternatives (wind rose, summary tables, frequency distributions and station metadata). The data lister provides for data download of archived data with a user password. ***Updated hourly.***

Climate, Ecosystem & Fire Applications (CEFA)

(http://cefa.dri.edu/raws/) provides hourly data as well. Enter a WIMS ID into this application to quickly export all hourly records dating back to when the solar radiation sensor was installed on that station. ***Updated monthly.***

Mesowest

(http://mesowest.utah.edu/index.html) provides access to hourly data for a wide variety of weather stations across the United States. Outputs include map displays, tables and graphs. For users that want to download quantities of data, consider its Mesonet API (https://synopticlabs.org/api/mesonet/), where both adhoc queries and programmable requests can be formatted. ***Updated hourly.***

Iowa Environmental Mesonet (IEM)

(https://mesonet.agron.iastate.edu/sites/locate.php) provides a range of products for a variety of networks around the world

Local Online resources

These and other resources should be considered and may be found by asking local managers and experts. Some examples include:

- Alaska Fire & Fuels (https://akff.mesowest.org/download/)
- Great Lakes Fire & Fuels (https://glff.mesowest.org/download/)
- OK-FIRE (http://okfire.mesonet.org/)

1.7.2 Critique and Edit in Firefamily Plus

Firefamily Plus is fire and weather analysis software that is freely available at http://www.firemodels.org and can be used effectively to review and edit archived weather records obtained from the sites listed above. Here are several steps that can help evaluate the weather record for time span, accuracy, and completeness. Once the records are imported:

1. Evaluate the Active Working Set for the archive to determine if the record has a sufficient time span (15+ years) for climatological analyses
2. Evaluate the completeness of the record by evaluating the data count for the archive. Does the station collect records year round? If not, what period of the year appears to have a relatively complete record?
3. Evaluate individual data elements to determine the archive's accuracy. Look for outliers among the basic data observations (Temp, RH, windspeed, precipitation, max & min values) by sorting records in ascending and descending order to locate erroneous values.
4. Evaluate data elements and calculated components and indices by displaying climatology graphs (max, min) and individual years to find erroneous trends and outliers.
5. Evaluate the wind rose to determine whether the station's wind observations (speeds and directions) are representative of the fire situation being analyzed.

It may be appropriate to edit the records, which can be done in the "View Observations" table. Before changing archived observation, the record in question should be compared to those of surrounding stations. Any changes made, should be documented for the local fire management agency.

1.8 Weather References

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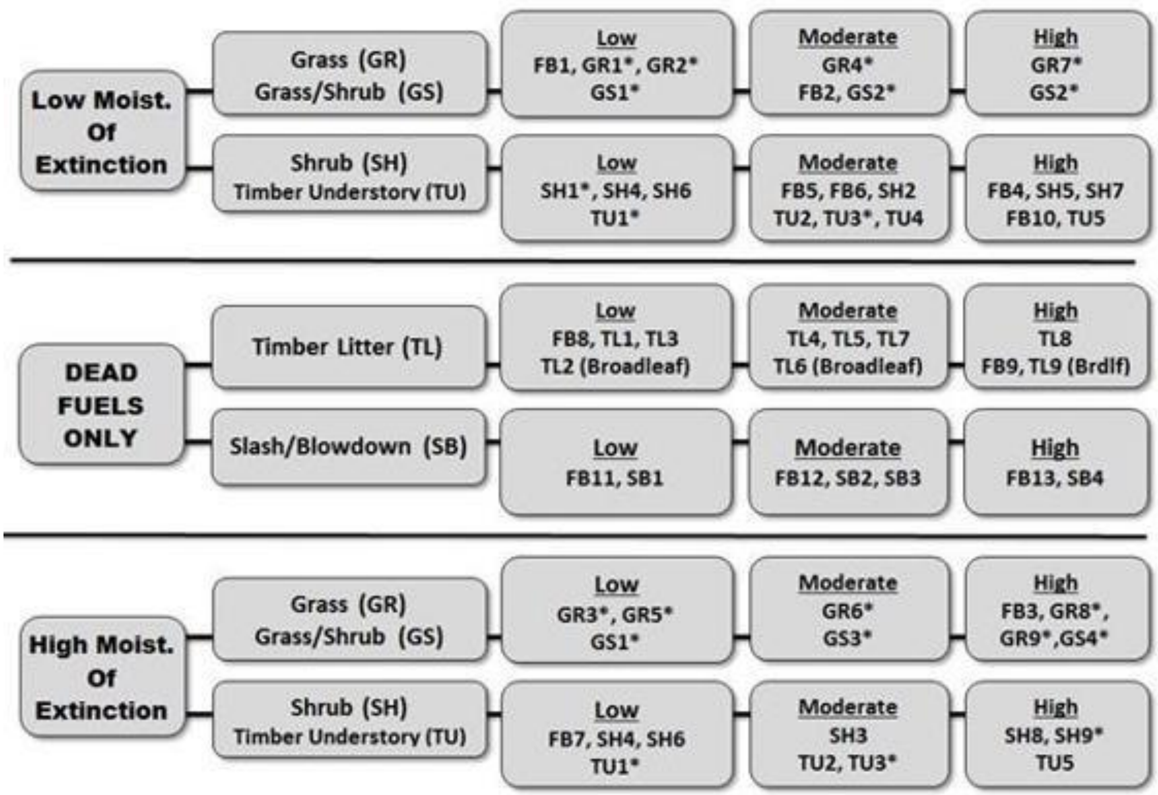
2. Fuels

2.1 Surface Fuel Model Selection

2.1.1 Fuel Model Selection Guide

In using this guide, these factors can guide users:

1. Do diurnal changes in fuel moisture conditions bound the burn period each day, excluding much of the evening, overnight, and morning hours? If the answer is yes, consider primarily ***Low Moisture of Extinction*** fuel models over High Moisture of Extinction models.
2. If specific fuelbeds seems unaffected by greenup and summer conditions, consider primarily ***dead fuels only*** fuel models during those periods.
3. Consider what is carrying surface fire (***Grass & Grass/Shrub, Shrub & Timber Understory, Timber Litter, or Slash/Blowdown***) and select several alternatives.
4. ***Dynamic Fuel Models*** (marked with *) allow greater variability due to seasonal transitions in live fuels. They are concentrated among the grass and grass shrub models primarily, due to the annual greenup and curing they experience. Note that SH1, SH9, TU1, and TU3 also include herbaceous fuel loads and are dynamic.
5. ***Low, Moderate, and High*** classifications within each group reflect relative Heat per Unit Area levels. Use this classification to help focus selections on several alternatives.



2.1.2 Surface Fuel Model Evaluation

Once several alternative fuel models have been selected as possibilities, evaluation of their fire behavior outputs (rate of spread and flame length) with typical or reference inputs is important. However, making several good fuel model selections is only a preliminary step in the calibration process.

Fire Behavior Class	Rate of Spread (ch/hr)	Flame Length (ft)
Very Low	0-2	0-1
Low	2-5	1-4
Moderate	5-20	4-8
High	20-50	8-12
Very High	50-150	12-25
Extreme	150+	25+

As suggested here, when comparing modeled and observed fire behavior, it may be helpful to think of spread rates and flame lengths in ranges or Fire Behavior Classes. If fireline personnel can effectively report observed fire behavior in these terms, differentiating what they see through the burn period and as environmental inputs change, the analysis will be improved dramatically.

Testing the range of a fuel model's characteristic fire behavior requires analysis of several environmental inputs. Consider these. BehavePlus, as a sensitivity tool, only allow consideration of two variables at a time. However, there are generally at least 3 significant environmental factors that govern the day-to-day variation in fire behavior; wind, slope, and fuel moisture. Fortunately, the Rothermel fire spread model depicts the effect of slope as an equivalent windspeed. If the calibration analysis represents the windspeed as a range of effective windspeed, slope should be at least generally incorporated. In some cases, it may still be necessary to consider its effect separately.

- ***1hr Moisture & Effective Windspeed***: The dominant factors wind, slope, and fuel moisture. Once a range of expected midflame windspeeds is established, it is possible to add the effect of slope by identifying the slope equivalent windspeed, producing a range of effective windspeeds for the calibration analysis.
- ***Live Herbaceous Moisture***: With other environmental inputs set at representative levels, evaluate the range of fire behavior produced between 30% and 120% live herbaceous fuel moisture for dynamic fuel models.
- ***Live Woody Moisture***: This consideration is critical for grass/shrub, shrub, and timber understory fuel models. Because there is no fuel load transfer in the live woody category, default ranges are characteristic of the current season. Set other environmental inputs at representative levels. Keep in mind that live woody moisture levels change rather slowly in most cases. Depending on the time of year and the drought situation, it may not be necessary to consider a wide range of moistures. However, it is critical that appropriate levels are identified for the analysis.
- ***Slope and Spread Direction***: Though this combination of factors is probably secondary in most cases, backing and flanking fire behavior related to slope reversals and prescribed fire ignitions may be important.

2.1.3 Two Sets of Surface Fuel Models

This guide integrates the original 13 models with the 40 standard models added in June of 2005. Though the developers of the 40 standard models intended that they stand alone, all 53 models are available to the user in current versions of all the fire modeling systems that are designed to use them. And though the original 13 models were grouped into only 4 carrier types, they can be effectively distributed into the 6 types defined with the newer set.

Consider the objectives that guided the development of these two sets.

The original 13 (Anderson, 1982) were designed to support analysis of:

- wildfires under peak fire conditions with cured herbaceous fuels.
- Sensitivity to live fuels is represented in only 5 of them, with large responses predominately in fuel models 4 and 5.
- They were designed before crown fire modeling was implemented, requiring that at least some of the 13 represent crown fire behavior.

On the other hand, the newer 40 standard fuel models (Scott and Burgan, 2001) were developed to:

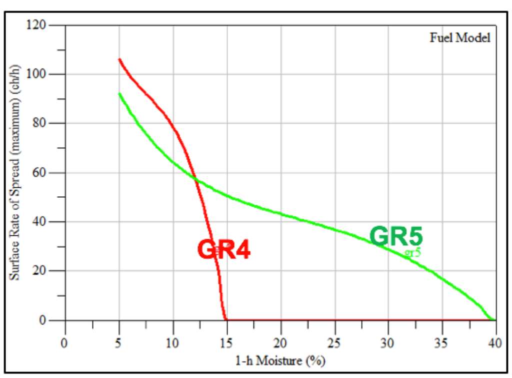
- facilitate analysis for fire use and fuel modification treatments.
- They are designed so that they can represent green, growing season conditions as well as cured, peak season conditions.

The most important benefit of integrating fuel model sets in this guide may be the context the original 13 provide for users familiar with them. Consider it something of a dual language guide, facilitating translation for those users.

2.1.4 Moisture of Extinction

When selecting a fuel model, one of the first considerations should be whether fuels are expected to burn under high fuel moisture conditions. Though many modeling tools allow the user to define a burn period which can truncate fire behavior even when moisture of extinction has not been reached, humid climate fuel models (with high moisture of extinction) will express significant fire behavior even when corresponding dry climate fuels estimate no fire spread.

The example here demonstrates that GR4 exhibits no fire spread at 15% fuel moisture and at that same point, GR5 can project spread rates of as much as 50 ch/hr. Ensure that the fuel model selected accurately represents potential fire spread and intensity under the range of fuel moistures conditions that will be encountered.



2.1.5 Fuel Model Parameters and Descriptions

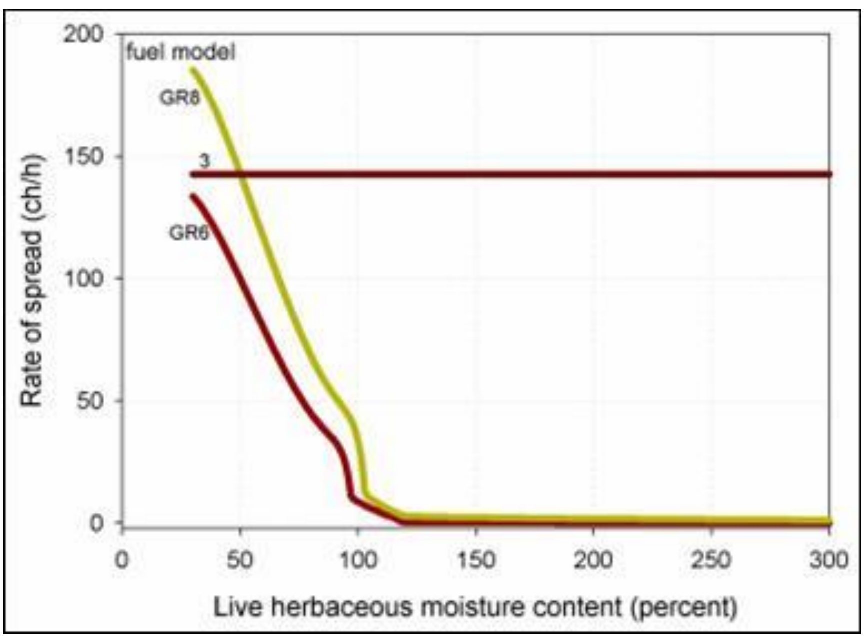
To insure accuracy and precision in modeling efforts, fuel model selection needs to employ a disciplined process. With the addition of 40 fuel models representing 6 carrier fuel types, users will be more likely to find an appropriate fuel model based on fuel model parameters, resulting in reasonable ranges of fire behavior over the range of anticipated environmental conditions.

- Looking at the fuel bed, what fuel type (GR, GS, SH, TU, TL, or SB) is observed (or expected) to carry fire spread? Keep in mind that there are analogous characteristics that can cross these fuel types. However, if your fuelbed has a significant canopy layer, it may be more descriptive to select a TU or TL fuel.
- Which fuel categories (1hr, 10hr, 100hr, Herb, Woody) are observed (or expected) to be available for burning in the flaming front under anticipated range of environmental conditions? Does one (or several) represent the distribution of fuel loads better than another?
- Is it a shallow or deep fuelbed? Will any shrub layer burn as part of the surface or canopy layer?
- Is the fuel model description a reasonable description of conditions encountered?

2.1.6 Dynamic (proportional) Fuel Load Transfer

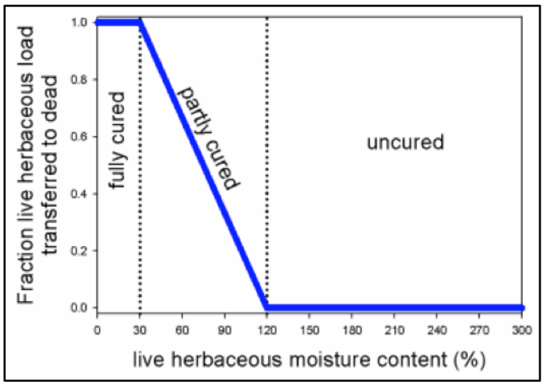
A feature that was implemented with the development of the National Fire Danger Rating System (NFDRS) recognizes that most herbaceous fuels transition between green and cured conditions over the course of a fire season. Effectively, this transfer of herbaceous fuel loads between live and dead categories redefines the fuel complex with each proportion transferred, making it a critical fuel model characteristic. The changes in output fire behavior can be dramatic, when compared to the static fuel models among the original 13.

The example here shows spread rate for dynamic fuels GR6 & GR8 with the corresponding static FB3 from the original set of 13.



In the development of the new set of fuel models, this “dynamic” (or proportional) fuel load transfer has been implemented for all fuel models that include herbaceous loads. It includes all grass, grass/shrub, two shrub (SH1 & SH9), and two timber understory (TU1 & TU3) models.

As depicted in the graph and table below, the fuel load transfer (implemented in FARSITE, FLAMMAP, and WFDSS Fire Behavior analysis tools) is dependent on the input herbaceous moisture content.



Herbaceous Moisture Content	Level of Curing (fuel load transferred)	
120% or more	0/1 cured	Uncured
98%	¼ cured	Partially cured
90%	1/3 cured	
75%	½ cured	
60%	2/3 cured	
53%	¾ cured	
30% or less	1/1 cured	Fully cured

- If input Live Herbaceous Moisture Content (LHMC) is 120% or higher, none of the load is transferred.
- If input LHMC is 30% or lower, the entire load is transferred to dead herbaceous fuel and the 1hr moisture content is assigned to it.
- If input LHMC is between 30% and 120%, part of the herbaceous load is transferred to dead load and is assigned the 1hr moisture content. The input LHMC that represents a particular portion of the load transferred from live to dead can be calculated using this equation and an assumed curing percentage:

$$input\,LHMC = 120 - (90 * fraction\ cured)$$

<u>Important cautions</u>: Between 90% and 100% input LHMC, very rapid changes in fire behavior outputs can occur. Be sure to test the sensitivity to this input. Though it is agreed that live fuels can provide a critical influence on fire behavior, serving as both the heat sink and heat source in varying combinations, the specifics are not well modeled or understood. There are findings that indicate that curing is not directly related to herbaceous moisture content. As a result, BehavePlus allows the user to input curing % separate from LHMC.

2.2 Surface Fuel Model Descriptions

2.2.1 Carrier Fuel Types

Non-burnable (NB) Fuels: The nonburnable "fuel models" are included on the next five pages to provide consistency in how the nonburnable portions of the landscape are displayed on a fuel model map. In all NB fuel models, there is no fuel load—wildland fire will not spread.

- **NB1 (091) – URBAN/SUBURBAN**; Fuel model NB1 consists of land covered by urban and suburban development. To be called NB1, the area under consideration must not support wildland fire spread. In some cases, areas mapped as NB1 may experience structural fire losses during a wildland fire incident; however, structure ignition in those cases is either house-to-house or by firebrands, neither of which is directly modeled using fire behavior fuel models. If sufficient inflammable vegetation surrounds structures such that wildland fire spread is possible, then choose a fuel model appropriate for the wildland vegetation rather than NB1.
- **NB2 (092) – SNOW/ICE;** Land covered by permanent snow or ice is included in NB2. Areas covered by seasonal snow can be mapped to two different fuel models: NB2 for use when snow-covered and another for use in the fire season.
- **NB3 (093) – AGRICULTURAL FIELD;** Fuel model NB3 is agricultural land maintained in a non-burnable condition; examples include irrigated annual crops, mowed or tilled orchards, and so forth. However, there are many agricultural areas that are not kept in a non-burnable condition. For example, grass is often allowed to grow beneath vines or orchard trees, and wheat or similar crops are allowed to cure before harvest; in those cases, use a fuel model other than NB3.
- **NB8 (098) – OPEN WATER;** Land covered by open bodies of water such as lakes, rivers and oceans.
- **NB9 (099) – BARE GROUND;** Land devoid of enough fuel to support wildland fire spread is covered by fuel model NB9. Such areas may include gravel pits, arid deserts with little vegetation, sand dunes, rock outcroppings, beaches, and so forth.

Grass (GR) Fuels: The primary carrier of fire in the GR fuel models is grass. Grass fuels can vary from heavily grazed grass stubble or sparse natural grass to dense grass more than 6 feet tall. Fire behavior varies from moderate spread rate and low flame length in the sparse grass to extreme spread rate and flame length in the tall grass models. While the FB fuel models are static, all of the GR fuel models are dynamic, meaning that their live herbaceous fuel load shifts from live to dead as a function of live herbaceous moisture content. The effect of live herbaceous moisture content on spread rate and intensity is very strong.

Grass/Shrub (GS) Fuels: The primary carrier of fire in the GS fuel models is grass and shrubs combined; both components are important in determining fire behavior. All GS fuel models are dynamic, meaning that their live herbaceous fuel load shifts from live to dead as a function of live herbaceous moisture content. The effect of live herbaceous moisture content on spread rate and intensity is strong, and depends on the relative amount of grass and shrub load in the fuel model.

Shrub (SH) Fuels: The primary carrier of fire in the shrub fuel models is live and dead shrub twigs and foliage in combination with dead and down shrub litter.

Fuel models SH1 and SH9 are dynamic, due to a small amount of herbaceous fuel loading in them. The effect of live herbaceous load transfer to dead fine fuel on spread rate and flame length can be significant in those two dynamic SH models.

Timber Understory (TU) Fuels: The primary carrier of fire in the TU fuel models is forest litter in combination with herbaceous or shrub fuels. TU1 and TU3 contain live herbaceous load and are dynamic, meaning that their live herbaceous fuel load is allocated between live and dead as a function of live herbaceous moisture content. The effect of live herbaceous moisture content on spread rate and intensity is strong, and depends on the relative amount of grass and shrub load in the fuel model.

Timber Litter (TL) Fuels: The primary carrier of fire in the TL fuel models is dead and down woody fuel. Live fuel, if present, has little effect on fire behavior.

Slash/Blow down (SB) Fuels: The primary carrier of fire in the SB fuel models is activity fuel or blow down. Forested areas with heavy mortality may be modeled with SB fuel models.

2.2.2 Grass & Grass Shrub Fuel Model Descriptions

(fuels in shaded rows: dynamic transfer of herb fuel load from live to dead)

Carrier	FM #	FM Code	Fuel Model Name	***Wind Adj***	1hr Load	10hr Load	100hr Load	Herb Load	Woody Load	***Total Load***	1hr SAV	Herb SAV	Woody SAV	***Bed Depth***	***Moist Extinct***	Dead Heat	Live Heat
Dry Climate Fuel Models																	
GR	1	FB1	Short grass	***0.36***	0.7	--	--	--	--	***0.7***	3500	--	--	***1.0***	***12***	8000	--
GR	2	FB2	Timber grass and understory	***0.36***	2.0	1.0	0.5	0.5	--	***4.0***	3000	1500	--	***1.0***	***15***	8000	8000
GR	101	GR1	Short, sparse dry climate grass	***0.31***	0.1	--	--	0.3	--	***0.4***	2200	2000	--	***0.4***	***15***	8000	8000
GR	102	GR2	Low load dry climate grass	***0.36***	0.1	--	--	1.0	--	***1.1***	2000	1800	--	***1.0***	***15***	8000	8000
GR	104	GR4	Moderate load dry climate grass	***0.42***	0.3	--	--	1.9	--	***2.2***	2000	1800	--	***2.0***	***15***	8000	8000
GR	107	GR7	High load dry climate grass	***0.46***	1.0	--	--	5.4	--	***6.4***	2000	1800	--	***3.0***	***15***	8000	8000
GS	121	GS1	low load dry climate grass-shrub	***0.35***	0.2	--	--	0.5	0.7	***1.4***	2000	1800	1800	***0.9***	***15***	8000	8000
GS	122	GS2	moderate load dry climate grass-shrub	***0.39***	0.5	0.5	--	0.6	1.0	***2.6***	2000	1800	1800	***1.5***	***15***	8000	8000
Humid Climate Fuel Models																	
GR	3	FB3	tall grass	***0.44***	3.0	--	--	--	--	***3.0***	1500	--	--	***2.5***	***25***	8000	--
GR	103	GR3	Low load very coarse humid climate grass	***0.42***	0.1	0.4	--	1.5	--	***2.0***	1500	1300	--	***2.0***	***30***	8000	8000
GR	105	GR5	low load humid climate grass	***0.39***	0.4	--	--	2.5	--	***2.9***	1800	1600	--	***1.5***	***40***	8000	8000
GR	106	GR6	moderate load humid climate grass	***0.39***	0.1	--	--	3.4	--	***3.5***	2200	2000	--	***1.5***	***40***	9000	9000
GR	108	GR8	High load very coarse humid climate grass	***0.49***	0.5	1.0	--	7.3	--	***8.8***	1500	1300	--	***4.0***	***30***	8000	8000
GR	109	GR9	very high load humid climate grass	***0.52***	1.0	1.0	--	9.0	--	***11.0***	1800	1600	--	***5.0***	***40***	8000	8000
GS	123	GS3	moderate load humid climate grass-shrub	***0.41***	0.3	0.3	--	1.5	1.3	***3.3***	1800	1600	1600	***1.8***	***40***	8000	8000
GS	124	GS4	high load humid climate grass-shrub	***0.42***	1.9	0.3	0.1	3.4	7.1	***12.8***	1800	1600	1600	***2.1***	***40***	8000	8000

Dry Climate Grass & Grass –Shrub Fuel Descriptions

FB1 (01): Fire spread is governed by the fine herbaceous fuels that are cured or nearly cured. Fires move rapidly through cured grass & associated material. Very little shrub or timber is present, generally less than one-third of the area. Grasslands & savanna are represented along with stubble, grass tundra, & grass-shrub combinations that meet the above area constraint. Annual & perennial grasses are included fuels.

FB2 (02): Fire spread is primarily through fine herbaceous fuels, either curing or dead. These are surface fires where the herbaceous material, besides litter and dead-down stem wood from the open shrub or timber overstory, contribute to the fire intensity. Open shrub lands and pine stands or scrub oak stands that cover one-third or two thirds of the area may generally fit this model, but may include clumps of fuels that generate higher intensities and may produce firebrands. Some pinyon-juniper may be in this model.

GR1 (101): This model uses dynamic transfer of herb fuel load from live to dead. The primary carrier of fire is sparse grass, though small amounts of fine dead fuel may be present. The grass in GR1 is generally short, either naturally or by heavy grazing, and may be sparse or discontinuous. Moisture of extinction of GR1 is indicative of dry climate fuelbeds, but may also be applied in high-extinction moisture fuelbeds, because in both cases predicted spread rate and flame length are low compared to other GR models

GR2 (102): Uses dynamic transfer of herb fuel load from live to dead. Primary carrier of fire is grass, though small amounts of fine dead fuel may be present. Load is greater than GR1. Fuelbed may be more continuous. Shrubs do not affect fire behavior.

GR4 (104): This model uses dynamic transfer of herb fuel load from live to dead. The primary carrier of fire is continuous, dry-climate grass. Load and depth are greater than GR2; fuelbed depth is about 2 feet.

GR7 (107): Uses dynamic transfer of herb fuel load from live to dead. Primary carrier is continuous dry-climate grass. Load & depth greater than GR4. Grass about 3 feet tall.

GS1 (121): This model uses dynamic transfer of herb fuel load from live to dead. The primary carrier of fire is grass and shrubs combined. Shrubs are about 1 foot high, grass load is low. Spread rate is moderate; flame length low. Moisture of extinction is low.

GS2 (122): Primary carrier is grass & shrubs combined. Shrubs are 1-3 feet high, grass load is moderate. Spread rate is high; flame length moderate. Moisture of extinction low.

Humid Climate Grass & Grass Shrub Fuel Descriptions

FB3 (03): Fires in this fuel are the most intense of the grass group and display high rates of spread under the influence of wind. The fire may be driven into the upper heights of the grass stand by the wind and cross standing water. Stands are tall, averaging about 3 ft., but may vary considerably. Approximately one-third or more of the stand is considered dead or cured and maintains the fire. Wild or cultivated grains that have not been harvested can be considered similar to tall prairie and marshland grasses.

GR3 (103): This model uses dynamic transfer of herb fuel load from live to dead. The primary carrier of fire is continuous, coarse, humid-climate grass. Grass and herb fuel load is relatively light; fuelbed depth is about 2 feet. Shrubs are not present in significant quantity to affect fire behavior.

GR5 (105): This model uses dynamic transfer of herb fuel load from live to dead. The primary carrier of fire is humid-climate grass. Load is greater than GR3 but depth is lower, about 1-2 feet.

GR6 (106): This model uses dynamic transfer of herb fuel load from live to dead. The primary carrier of fire is continuous humid-climate grass. Load is greater than GR5 but depth is about the same. Grass is less coarse than GR5.

GR8 (108): This model uses dynamic transfer of herb fuel load from live to dead. The primary carrier of fire is continuous, very coarse, humid-climate grass. Load and depth are greater than GR6. Spread rate and flame length can be extreme if grass is fully cured.

GR9 (109): This model uses dynamic transfer of herb fuel load from live to dead. The primary carrier of fire is dense, tall, humid-climate grass. Load and depth are greater than GR8, about 6 feet tall. Spread rate and flame length can be extreme if grass is fully or mostly cured.

GS3 (123): This model uses dynamic transfer of herb fuel load from live to dead. The primary carrier of fire is grass and shrubs combined. Moderate grass/shrub load, average grass/shrub depth less than 2 feet. Spread rate is high; flame length moderate. Moisture of extinction is high.

GS4 (124): The primary carrier of fire is grass and shrubs combined. Heavy grass/shrub load, depth greater than 2 feet. Spread rate high; flame length very high. Moisture of extinction is high.

2.2.3 Shrub and Timber Understory Fuel Model Descriptions

(fuels in shaded rows: dynamic transfer of herb fuel load from live to dead)

Carrier	FM #	FM Code	Fuel Model Name	***Wind Adj***	1hr Load	10hr Load	100hr Load	Herb Load	Woody Load	***Total Load***	1hr SAV	Herb SAV	Woody SAV	***Bed Depth***	***Moist Extinct***	Dead Heat	Live Heat
			Dry Climate Fuel Models														
SH	4	FB4	chaparral	***0.55***	5.0	4.0	2.0	--	5.0	***16.0***	2000	--	1500	***6***	***20***	8000	8000
SH	5	FB5	brush	***0.42***	1.0	0.5	--	--	2.0	***3.5***	2000	--	1500	***2***	***20***	8000	8000
SH	6	FB6	dormant brush	***0.44***	1.5	2.5	2.0	--	--	***6.0***	1750	--	--	***2.5***	***25***	8000	--
SH	141	SH1	low load dry climate shrub	***0.36***	0.3	0.3	0.0	0.2	1.3	***2.0***	2000	1800	1600	***1***	***15***	8000	8000
SH	142	SH2	mod. load dry climate shrub	***0.36***	1.4	2.4	0.8	--	3.9	***8.4***	2000	--	1600	***1***	***15***	8000	8000
SH	145	SH5	high load dry climate shrub	***0.55***	3.6	2.1	--	--	2.9	***8.6***	750	--	1600	***6***	***15***	8000	8000
SH	147	SH7	very high load dry climate shrub	***0.55***	3.5	5.3	2.2	--	3.4	***14.4***	750	--	1600	***6***	***15***	8000	8000
TU	161	TU1	light load dry climate timber-grass-shrub	***0.33***	0.2	0.9	1.5	0.2	0.9	***3.7***	2000	1800	1600	***0.6***	***20***	8000	8000
TU	164	TU4	dwarf conifer with understory	***0.32***	4.5	--	--	--	2.0	***6.5***	2300	--	2000	***0.5***	***12***	8000	8000
TU	165	TU5	very high load dry climate timber-shrub	***0.33***	4.0	4.0	3.0	--	3.0	***14.0***	1500	--	750	***1***	***25***	8000	8000
TU	10	FB10	timber litter and understory	***0.36***	3.0	2.0	5.0	--	2.0	***12.0***	2000	--	1500	***1***	***25***	8000	8000
			Humid Climate Fuel Models														
SH	7	FB7	southern rough	***0.44***	1.1	1.9	1.5	--	0.4	***4.9***	1750	--	1500	***2.5***	***40***	8000	8000
SH	143	SH3	mod. load humid climate shrub	***0.44***	0.5	3.0	--	--	6.2	***9.7***	1600	--	1400	***2.4***	***40***	8000	8000
SH	144	SH4	low load humid climate timber-shrub	***0.46***	0.9	1.2	0.2	--	2.6	***4.8***	2000	--	1600	***3***	***30***	8000	8000
SH	146	SH6	low load humid climate shrub	***0.42***	2.9	1.5	--	--	1.4	***5.8***	750	--	1600	***2***	***30***	8000	8000
SH	148	SH8	high load humid climate shrub	***0.46***	2.1	3.4	0.9	--	4.4	***10.7***	750	--	1600	***3***	***40***	8000	8000
SH	149	SH9	very high load humid climate shrub	***0.50***	4.5	2.5	--	1.6	7.0	***15.5***	750	1800	1500	***4.4***	***40***	8000	8000
TU	162	TU2	Moderate load humid climate timber-shrub	***0.36***	1.0	1.8	1.3	--	0.2	***4.2***	2000	--	1600	***1***	***30***	8000	8000
TU	163	TU3	moderate load humid climate timber-grass-shrub	***0.38***	1.1	0.2	0.3	0.7	1.1	***3.3***	1800	1600	1400	***1.3***	***30***	8000	8000

Dry Climate Shrub & Timber Understory Fuel Descriptions

FB4 (04): Fire intensity and fast-spreading fires involve the foliage and live and dead fine woody material in the shrub layer. Besides flammable foliage, there is dead woody material that significantly contributes to fire intensity. Deep litter layer may also confound suppression efforts.

FB5 (05): Primary carrier is litter cast by the shrubs, and the grasses or forbs in the understory. Shrubs are generally not tall, but have nearly total coverage of the area. Young, green stands with no deadwood.

FB6 (06): Fire carries through the shrub layer, requiring at least moderate winds. Fire will drop to the ground at low windspeeds or openings in the stand. The shrubs are older. A broad range of shrub conditions is included here.

SH1 (141): This model uses dynamic transfer of herb fuel load from live to dead. The primary carrier of fire in SH1 is woody shrubs and shrub litter. Low shrub fuel load, fuelbed depth about 1 foot; some grass may be present. Spread rate is very low; flame length very low.

SH2 (142): The primary carrier of fire in SH2 is woody shrubs and shrub litter. Moderate fuel load (higher than SH1), depth about 1 foot, and no grass fuel present. Spread rate is low; flame length low.

SH5 (145): The primary carrier of fire in GS4 is grass and shrubs combined. Heavy grass/shrub load, depth greater than 2 feet. Spread rate very high; flame length very high. Moisture of extinction is high.

SH7 (147): The primary carrier of fire is woody shrubs and shrub litter. Very heavy shrub load, depth 4-6 feet. Spread rate lower than SH5, but flame length similar. Spread rate is high; flame length very high.

FB10 (10): Dead down fuels include greater quantities of 3-inch or larger limbwood resulting from overmaturity or natural events that create a large load of dead material. Crown fire and spotting is more frequent in this fuel situation.

TU1 (161): This model uses dynamic transfer of herb fuel load from live to dead. The primary carrier of fire in is low load of grass and/or shrub with litter. Spread rate is low; flame length low.

TU4 (164): The primary carrier of fire is grass, lichen or moss understory plants. If live woody moisture content is set to 100 percent, this fuel model mimics the behavior of Norum's (1982) empirical calibration for Alaska Black Spruce. Spread rate is moderate; flame length moderate.

TU5 (165): The primary carrier of fire in TU5 is heavy forest litter with a shrub or small tree understory. Spread rate is moderate; flame length moderate.

Humid Climate Shrub & Timber Understory Fuel Descriptions

FB7 (07): Fires burn through the surface and shrub strata with equal ease and can occur at higher dead fuel moisture contents because of the flammable nature of live foliage and other live material. Stands of shrubs are generally between 2 and 6 ft. high. Palmetto-gallberry understory within pine overstory sites are typical and low pocosins may be represented. Black spruce-shrub combinations in Alaska may also be represented.

SH3 (143): The primary carrier of fire in SH3 is woody shrubs and shrub litter. Moderate shrub load, possibly with pine overstory or herbaceous fuel, fuel bed depth 2-3 feet. Spread rate is low; flame length low.

SH4 (144): The primary carrier of fire in SH4 is woody shrubs and shrub litter. Low to moderate shrub and litter load, possibly with pine overstory, fuel bed depth about 3 feet. Spread rate is high; flame length moderate.

SH6 (146): The primary carrier of fire in SH6 is woody shrubs and shrub litter. Dense shrubs, little or no herbaceous fuel, fuelbed depth about 2 feet. Spread rate is high; flame length high.

SH8 (148): The primary carrier of fire in SH8 is woody shrubs and shrub litter. Dense shrubs, little or no herbaceous fuel, fuelbed depth about 3 feet. Spread rate is high; flame length high.

SH9 (149): This model uses dynamic transfer of herb fuel load from live to dead. The primary carrier of fire in SH9 is woody shrubs and shrub litter. Dense, finely branched shrubs with significant fine dead fuel, about 4-6 feet tall; some herbaceous fuel may be present. Spread rate is high, flame length very high.

TU2 (162): The primary carrier of fire in TU2 is moderate litter load with shrub component. High extinction moisture. Spread rate is moderate; flame length low.

TU3 (163): This model uses dynamic transfer of herb fuel load from live to dead. The primary carrier of fire in TU3 is moderate forest litter with grass and shrub components. Extinction moisture is high. Spread rate is high; flame length moderate.

2.2.4 Timber Litter and Slash/Blowdown Fuel Model Descriptions

Carrier	FM #	FM Code	Fuel Model Name	***Wind Adj***	1hr Load	10hr Load	100hr Load	Herb Load	Woody Load	***Total Load***	1hr SAV	Herb SAV	Woody SAV	***Bed Depth***	***Moist Extinct***	Dead Heat	Live Heat
Timber Litter Fuel Models																	
TL	8	FB8	compact timber litter	***0.28***	1.5	1.0	2.5	--	--	***5.0***	2000	--	--	***0.2***	***30***	8000	--
TL	9	FB9	hardwood litter	***0.28***	2.9	0.4	0.2	--	--	***3.5***	2500	--	--	***0.2***	***25***	8000	--
TL	181	TL1	Low load compact conifer litter	***0.28***	1.0	2.2	3.6	--	--	***6.8***	2000	--	--	***0.2***	***30***	8000	--
TL	182	TL2	low load broadleaf litter	***0.28***	1.4	2.3	2.2	--	--	***5.9***	2000	--	--	***0.2***	***25***	8000	--
TL	183	TL3	moderate load conifer litter	***0.29***	0.5	2.2	2.8	--	--	***5.5***	2000	--	--	***0.3***	***20***	8000	--
TL	184	TL4	Small downed logs	***0.31***	0.5	1.5	4.2	--	--	***6.2***	2000	--	--	***0.4***	***25***	8000	--
TL	185	TL5	high load conifer litter	***0.33***	1.2	2.5	4.4	--	--	***8.1***	2000	--	--	***0.6***	***25***	8000	--
TL	186	TL6	moderate load broadleaf litter	***0.29***	2.4	1.2	1.2	--	--	***4.8***	2000	--	--	***0.3***	***25***	8000	--
TL	187	TL7	Large downed logs	***0.31***	0.3	1.4	8.1	--	--	***9.8***	2000	--	--	***0.4***	***25***	8000	--
TL	188	TL8	long-needle litter	***0.29***	5.8	1.4	1.1	--	--	***8.3***	1800	--	--	***0.3***	***35***	8000	--
TL	189	TL9	very high load broadleaf litter	***0.33***	6.7	3.3	4.2	--	--	***14.1***	1800	--	--	***0.6***	***35***	8000	--
Slash/Blowdown Fuel Models																	
SB	11	FB11	light slash	***0.36***	1.5	4.5	5.5	--	--	***11.5***	1500	--	--	***1.0***	***15***	8000	--
SB	12	FB12	medium slash	***0.43***	4.0	14.0	16.5	--	--	***34.6***	1500	--	--	***2.3***	***20***	8000	--
SB	13	FB13	heavy slash	***0.46***	7.0	23.0	28.1	--	--	***58.1***	1500	--	--	***3.0***	***25***	8000	--
SB	201	SB1	low load activity fuel	***0.36***	1.5	3.0	11.0	--	--	***15.5***	2000	--	--	***1.0***	***25***	8000	--
SB	202	SB2	moderate load activity or low load blowdown	***0.36***	4.5	4.3	4.0	--	--	***12.8***	2000	--	--	***1.0***	***25***	8000	--
SB	203	SB3	high load activity fuel or moderate load blowdown	***0.38***	5.5	2.8	3.0	--	--	***11.3***	2000	--	--	***1.2***	***25***	8000	--
SB	204	SB4	high load blowdown	***0.45***	5.3	3.5	5.3	--	--	***14.0***	2000	--	--	***2.7***	***25***	8000	--

Timber Litter Fuel Descriptions

FB8 (08): Slow-burning ground fires with low flame heights are the rule, although the fire may encounter an occasional "jackpot" or heavy fuel concentration that can flare up. Only under severe weather conditions involving high temperatures, low humidities, and high winds do the fuels pose fire hazards. This layer is mainly needles, leaves, and some twigs since little undergrowth is present in the stand.

FB9 (09): Fire runs through the surface litter faster than FB8 and have higher flame height. Both long-needle conifer & hardwood stands, especially the oak-hickory types, are typical. Fall fires in hardwoods are representative, but spotting by rolling and blowing leaves in high winds will cause higher rates of spread than predicted. Concentrations of dead-down woody material will contribute to torching & spotting.

TL1 (181): The primary carrier of fire is compact forest litter. Light to moderate load, fuels 1-2 inches deep. May be used to represent a recently burned forest. Spread rate is very low; flame length very low.

TL2 (182): The primary carrier of fire is broadleaf (hardwood) litter. Low load, compact litter. Spread rate is very low; flame length very low.

TL3 (183): The primary carrier of fire is moderate load conifer litter, light load of coarse fuels. Spread rate is very low; flame length low.

TL4 (184): The primary carrier of fire is moderate load of fine litter and coarse fuels. Includes small diameter downed logs. Spread rate is low; flame length low.

TL5 (185): The primary carrier of fire is High load conifer litter; light slash or mortality fuel. Spread rate is low; flame length low.

TL6 (186): The primary carrier of fire is moderate load broadleaf litter, less compact than TL2. Spread rate is moderate; flame length low.

TL7 (187): The primary carrier of fire is heavy load forest litter, includes larger diameter downed logs. Spread rate low; flame length low.

TL8 (188): The primary carrier of fire in is moderate load long-needle pine litter, may include small amount of herbaceous load. Spread rate is moderate; flame length low.

TL9 (189): The primary carrier of fire is very high load, fluffy broadleaf litter. Can also be used to represent heavy needle-drape. Spread rate is moderate; flame length moderate.

Slash Blowdown Fuel Descriptions

FB11 (11): Fires are fairly active in the slash and intermixed herbaceous material. The spacing of the rather light fuel load, shading from overstory, or the aging of the fine fuels can contribute to limiting the fire potential. The less-than-3-inch material load is less than 12 tons per acre. The greater-than-3-inch material is represented by not more than 10 pieces, 4 inches in diameter, along a 50-ft transect.

FB12 (12): Rapidly spreading fires with high intensities capable of generating firebrands can occur. When fire starts, it is generally sustained until a fuel break or change in fuels is encountered. The visual impression is dominated by slash, most of it less than 3 inches in diameter. Fuels total less than 35 tons per acre & seem well distributed.

FB13 (13): Fire is generally carried across the area by a continuous layer of slash. Large quantities of greater-than-3-inch material are present. Active flaming is sustained for long periods and firebrands of various sizes may be generated. These contribute to spotting problems. Situations where the slash still has "red" needles attached but the total load is lighter, more like model 12, can be represented because of the earlier high intensity and quicker area involvement.

SB1 (201): Primary carrier of fire is light dead & down activity fuel. Fine fuel load is 10 to 20 t/ac, weighted toward fuels 1-3 in diameter class, depth is less than 1 foot. Spread rate is moderate; flame length low.

SB2 (202): The primary carrier of fire is moderate dead and down activity fuel or light blowdown. Fine fuel load is 7 to 12 t/ac, evenly distributed across 0-0.25, 0.25-1, and 1-3 inch diameter classes, depth is about 1 foot. Blowdown is scattered, with many trees still standing. Spread rate is moderate; flame length moderate.

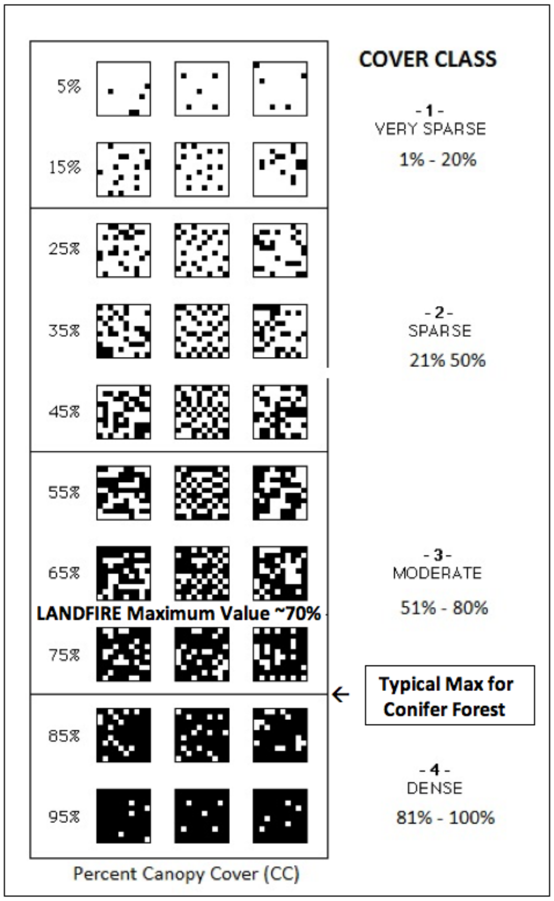
SB3 (203): The primary carrier of fire is heavy dead and down activity fuel or moderate blowdown. Fine fuel load is 7 to 12 t/ac, weighted toward 0-0.25 inch diameter class, depth is more than 1 foot. Blowdown is moderate; trees compacted to near the ground. Spread rate is high; flame length high.

SB4 (204): The primary carrier of fire is heavy blowdown fuel. Blowdown is total, fuelbed not compacted, most foliage and fine fuel still attached to blowdown. Spread rate very high; flame length very high.

2.3 Canopy Fuel Characteristics

2.3.1 Canopy Cover, % or Class

The Forest Canopy Cover (CC) describes the percent cover or cover class of the tree canopy in a stand. Specifically, canopy cover describes the vertical projection of the tree canopy onto an imaginary horizontal surface representing the ground's surface**. Estimate of Canopy Cover is used in adjustment of 20ft winds to mid-flame, in fuel moisture conditioning, and in spotting distance models**. The scale to the right illustrates the look of representative canopy cover percentages and ranges within each cover class.



Canopy Cover (CC), along with cloud cover, determines **shading** for fuel moisture estimates

For Surface Fuels sheltered by a forest canopy on flat terrain (Scott 2007)	
Canopy Cover	**Wind Sheltering**
CC ≤ 5%	Unsheltered
5% < CC ≤ 10%	Partially Sheltered
10% < CC ≤ 15%	
15% < CC ≤ 30%	Fully Sheltered, Open
30% < CC ≤ 50%	
CC > 50%	Fully Sheltered, closed

2.3.2 Stand (Canopy) Height, ft or m

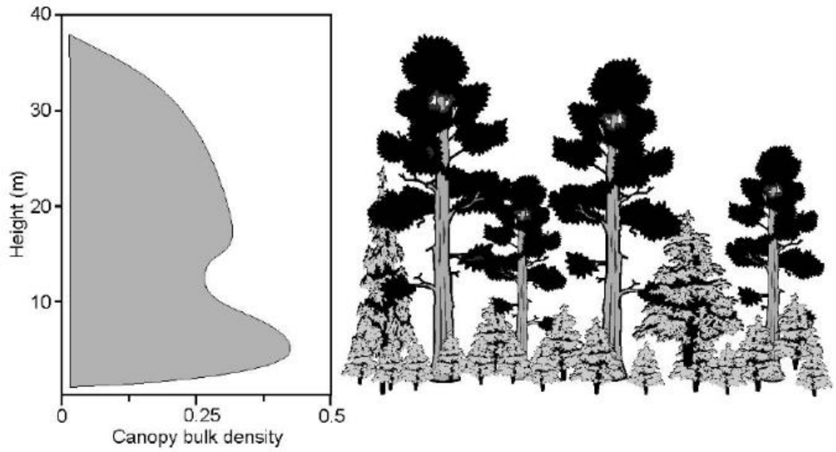
The Stand, or Canopy, Height (SH) describes the average height of the top of the vegetated canopy. Canopy Height estimates are used in adjustment of 20ft winds to mid-flame and in spotting distance models**.**

2.3.3 Canopy Base Height, ft or m

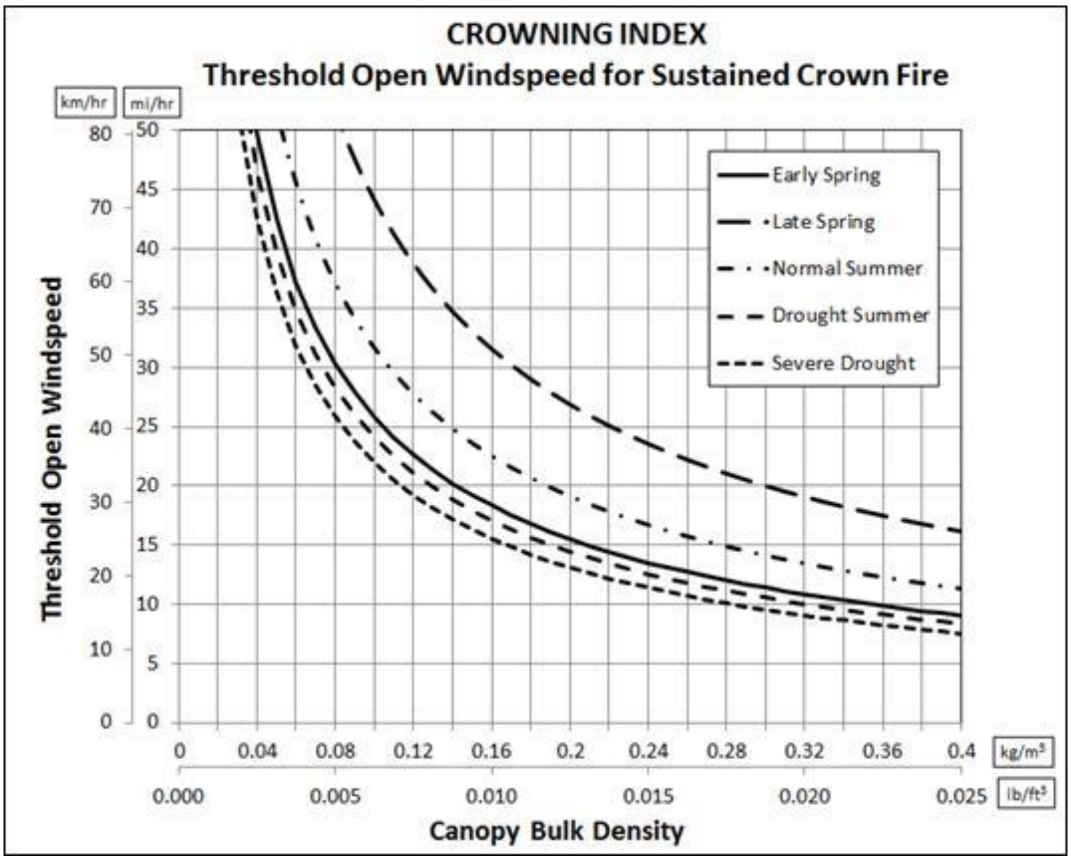
The Forest Canopy Base Height (CBH) describes the average height from the ground to a forest stand's canopy bottom. Specifically, it is the lowest height in a stand at which there is a sufficient amount of forest canopy fuel to propagate fire vertically into the canopy. Using this definition, ladder fuels such as lichen, dead branches, and small trees are incorporated. **Estimate of Canopy Base Height is used in the Crown Fire Initiation model.**

2.3.4 Canopy Bulk Density, kg/m³ or lb/ft³

The Forest Canopy Bulk Density (CBD) describes the density of available canopy fuel in a stand. It is defined as the mass of available canopy fuel per canopy volume unit**.** Typical units are either kg/m³ (LANDFIRE default) or lb/ft³ (BehavePlus default). **Canopy Bulk Density estimates are used to determine the threshold spread rate (or surface windspeed) used to determine the likelihood of active crown fire.**



This graph, also displayed in the Crown Fire section, displays the threshold surface 20ft windspeed, or Crowning Index, necessary for producing active crown fire given a specific canopy bulk density**.**



2.4 Landscape (lcp) Acquisition, Critique, & Editing (ACE)

2.4.1 Primary Reference

Stratton, Richard D. 2009. Guidebook on LANDFIRE fuels data acquisition, critique, modification, maintenance, and model calibration. Gen. Tech. Rep. RMRS-GTR-220. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 54 p. (http://www.fs.fed.us/rm/pubs/rmrs_gtr220.pdf)

2.4.2 LCP Data Sources

LANDFIRE Data Distribution Site: https://www.landfire.gov/viewer/

There are several versions of LANDFIRE data, including LCP files (2001, 2008, 2010, 2012, and 2014). You can evaluate what is available in each version with its Version Comparison Table (http://www.landfire.gov/version_comparison.php). There is no online tool for editing the files before download. Downloaded files may be requested in either the US Albers or the local UTM projection.

Wildland Fire Decision Support System (WFDSS): http://wfdss.usgs.gov

Analysis tools in WFDSS (Basic, STFB, NTFB, and FSPro) include downloadable LCP files. Users may edit the LCP files before download. Downloaded files come with a custom Albers projection that may require some reprojection effort before combining with shapefiles in FARSITE and FLAMMAP analysis. LCP Critique reports are available alongside the LCP file.

Interagency Fuel Treatment Decision Support System (IFTDSS):
https://iftdss.firenet.gov/iftdss/home

IFTDSS uses spatial analysis tools in support of Hazard Analysis, Prescribed Burn Planning, Risk Assessment, Fuels Treatment, and Fire Effects planning. Primarily based on the FLAMMAP processor, analysis tools use LANDFIRE data, allowing the user to edit and download LCPs from their projects.

2.4.3 Other Data Sources

Following is a list of GIS layers for fuels critique, modifications, and model calibration

Wildland Fire/Treatment History	**Socio-economic Considerations**
• Burn severity layers • Fire progression layers • Fuel treatments • Prescribed fire perimeters • Wildfire perimeters **Ecological Considerations** • Areas of critical environmental concern • Sensitive or critical wildlife habitat • Threatened, endangered, and sensitive (TES) flora and fauna habitat • Rivers and streams • Water bodies • Vegetation or cover-type classification	• Ownership & jurisdiction layer • Historical and recreational sites • Primary and secondary residences • Remote automated weather stations (RAWS) • Roads & Trails • Urban development **Other Base Layers** • Aerial photos • Digital orthophoto quad (DOQ) or quarter quad (DOQQ) • Digital raster graph (DRG)

2.4.4 LCP Fuel Themes

Layer/Theme	LANDFIRE Units	Primary References
Surface Fuel Model	**1-13** **91-99 (barriers)**	Anderson, H. E. 1982. Aids to determining fuel models for estimating fire behavior. Gen. Tech. Rep. INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 22 p. http://www.fs.fed.us/rm/pubs_int/int_gtr122.pdf
	101-204 **91-99 (barriers)**	Scott, Joe H.; Burgan, Robert E. 2005. Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model. Gen. Tech. Rep. RMRS-GTR-153. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 72 p. http://www.treesearch.fs.fed.us/pubs/9521
Canopy Cover (CC)	**Percent, 0-100%** 70% practical max	Scott, Joe H.; Reinhardt, Elizabeth D. 2005. Stereo photo guide for estimating canopy fuel characteristics in conifer stands. Gen. Tech. Rep. RMRS-GTR-145. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 49 p. http://www.treesearch.fs.fed.us/pubs/8473 http://www.landfire.gov/notifications16.php
Canopy Height (CH or SH)	**Meters, *10**	
Canopy Base Height (CBH)	**Meters, *10**	
Canopy Bulk Density (CBD)	**Kilograms/meter^3, *100**	

2.4.5 Nomenclature for Spatial Data Layers

Fuel Type	Fuel Model Bloc	Pre-Defined	Reserved for future pre-defined models	Available for Custom fuel Models
FB	01-13	01-13	--	--
Custom	14-89	---	--	14-89
NB	90-99	91-93, 98-99	94, 95	90, 96, 97
GR	100-119	101-109	110-112	100, 113-119
GS	120-139	121-124	125-130	120, 131-139
SH	140-159	141-149	150-152	140, 153-159
TU	160-179	161-165	166-170	160, 171-179
TL	180-199	181-189	190-192	180, 193-199
SB	200-219	201-204	205-210	200, 211-219
Custom	220-256	--	--	220-256

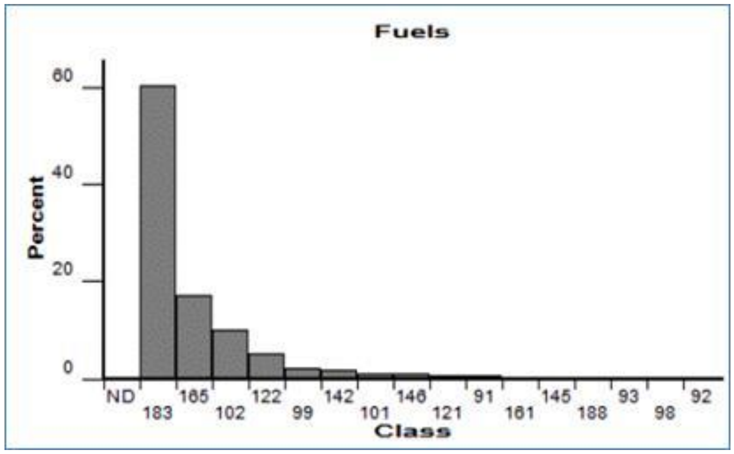
2.4.6 LCP Critique

The LCP Critique report is an essential element in the calibration process. It can be obtained from the same WFDSS analysis landscape tab that the LCP was obtained from. Or, if the LCP is downloaded, it can be loaded in FLAMMAP and a critique can be generated from there. There is a stand-alone version (LCPCritique) available at https://www.frames.gov/catalog/11606.

On the first page:

- View the filename, latitude, cell resolution, and coordinate system in the header information to insure the file used is correct
- View the Theme units, ranges, and value distributions to make sure that the lcp is valid and that there is no corrupted data.
- Determine the important surface fuel models in the LCP.

As an example, this histogram shows that fuel models 183, 165, 102, and 122 are the primary surface fuels.



Is that what you expect? What are the critical inputs for each of these fuel models? Are any of them dynamic?

Image & legend pages for each Theme

Some data problems can be identified visually here, such as vertical and horizontal lines in slope themes. The fuel model image can be reviewed by comparing mapped fuel models with areas that have had ground verification or high confidence classifications.

Theme Distributions for each Surface Fuel Models (in order by importance)

- Evaluate the terrain theme ranges and distributions for elevation, slope, & aspect. Are these appropriate for the fuel model? How would you revise or adjust them? Consider whether the fuel model needs to be changed for certain terrain value combinations.
- Canopy characteristics should be evaluated carefully to ensure that canopy cover (wind adjustment, fuel shading), tree heights (wind adjustment, spotting distance), and canopy base height (crown fire initiation), distributions make sense for the specific fuel model.
- Canopy bulk density (active crown fire propagation) values are not only related to the fuel model and canopy tree species, they also must be appropriately scaled for the crown fire propagation model used (surface fire control - Finney vs. crown fire control - Scott & Reinhardt; see crown fire topic in Section 5 (Fire Behavior).

2.4.7 Editing and Updating the Landscape (LCP) File

Any errors or necessary adjustments identified here should be included in landscape edits performed before the first analyses are conducted.

There are several means and tools for editing LCP files:

- WFDSS Analysis “Landscape Edit”
- IFTDSS Run’s “Landscape Review”
- FARSITE “Landscape Calculator”
- WFMRDA Fuels & Fire Ecology Tools at https://www.frames.gov/partner-sites/wfmrda-ffe/tools/current-resources/
- ESRI raster editing tools.

2.5 References

2.5.1 Online Resources

LANDFIRE US National Geo-spatial layers for vegetation, fuel, disturbance, etc., https://www.landfire.gov/index.php

WFMRDA Fuels & Fire Ecology Tools at https://www.frames.gov/partner-sites/wfmrda-ffe/tools/current-resources/

2.5.2 Publications

Anderson, H. E. 1982. Aids to determining fuel models for estimating fire behavior. Gen. Tech. Rep. INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 22 p.

Andrews, Patricia L. 2009. BehavePlus fire modeling system, version 5.0: Variables. Gen. Tech. Rep. RMRS-GTR-213 Revised. Fort Collins, CO; Department of Agriculture, Forest Service, Rocky Mountain Research Station. 111 p.

Bradshaw, Larry S.; Deeming, John E.; Burgan, Robert E.; Cohen, Jack D., compilers. The 1978 National Fire-Danger Rating System: technical documentation. General Technical Report INT-169. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984. 44 p.

Burgan, Robert E. 1987. Concepts and interpreted examples in advanced fuel modeling. Gen. Tech. Rep. INT-238. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 40 p.

Keane, Robert E.; Garner, Janice L.; Schmidt, Kirsten M.; Long, Donald G.; Menakis, James P.; Finney, Mark A. 1998. Development of input data layers for the FARSITE fire growth model for the Selway-Bitterroot Wilderness Complex, USA. Gen. Tech. Rep. RMRSGTR- 3. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 66 p.

Keane, Robert E.; Mincemoyer, Scott A.; Schmidt, Kirsten M.; Long, Donald G.; Garner, Janice L. 2000. Mapping vegetation and fuels for fire management on the Gila National Forest Complex, New Mexico, [CD-ROM]. Gen. Tech. Rep. RMRS-GTR-46-CD. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 126 p.

Keane, R.E; Reinhardt, E.D.; Scott, J.; Gray, K.; Reardon, J. 2004. Estimating Forest Canopy Bulk Density using six indirect methods. Can. J. For. Res. 35: 724-739.

Rothermel, R. C. 1972. A mathematical model for predicting fire spread in wildland fuels. Res. Pap. INT-115. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 40 p.

Rothermel, R. C. 1983. How to predict the spread and intensity of forest and range fires. Gen. Tech. Rep. INT-143. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 161 p

Scott, J.H. and Reinhardt, E.D. 2002. Estimating Canopy Fuels in Conifer Forests. Forest Management Today. 62(4):45-50.

Scott, Joe H.; Burgan, Robert E. 2005. Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model. Gen. Tech. Rep. RMRS-GTR-153. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 72 p.

Scott, Joe H. 2007. Nomographs for estimating surface fire behavior characteristics. Gen. Tech. Rep. RMRS-GTR-192. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 119 p.

Stratton, Richard D. 2009. Guidebook on LANDFIRE fuels data acquisition, critique, modification, maintenance, and model calibration. Gen. Tech. Rep. RMRS-GTR-220. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 54 p.

3. Fuel Moisture

3.1 Dead Fuel Moisture Content & Probability of Ignition

3.1.1 Nelson Model 1- and 10-hr Fuel Moisture Estimation Methods

Ralph M. Nelson (2000) developed a fuel moisture model for estimating the diurnal fuel moisture changes in a 10-hr NFDRS fuel stick. Requiring hourly observations, it produces a more dynamic estimate that better reflects changes in precipitation, humidity and sunshine. ***2016 NFDRS uses this methodology***.

Called SimpleFFMC, 1-hr Fuel Moisture Estimation Tables have been calibrated for the southeastern US by W. Matt Jolly (2016) and a web-app is available for online users at http://www.wfas.net/ffmc/

3.1.2 Fosberg Model 1-hr Fuel Moisture Estimation Methods

Michael A. Fosberg and John E. Deeming (1971) documented procedures for estimating 1- and 10-hour Timelag Fuel Moistures. This methodology, along with seasonal adjustment tables, were integrated into Richard Rothermel's (1983) tools and methods for surface fire behavior predictions. ***78/88 NFDRS use this.***

Day Time Estimation Procedure:

1. Using **Table A**, determine Reference Fuel Moisture (RFM) % from intersection of temperature & relative humidity. Record this RFM percentage.
2. Select **Table B, C, or D** to adjust RFM for local conditions by finding current month in table title.
3. Is the fine fuel more than 50% shaded by canopies and clouds? If yes, use bottom **(shaded)** portion of table. If no, use top **(Exposed)** portion of table.
4. **Determine the appropriate row based on aspect and slope**.
5. **Determine the appropriate column based on time of day & elevation** of area of concern when compared to the wx site elevation. Use **(A)bove** if the fire is 1-2000' above your location, **(B)elow** if the fire is 1-2000' below you, and **(L)evel** if the fire is within 1000' above or below you.
6. Obtain the 1-hr Moisture Content Correction (%) from the intersection of row & column.
7. Add the resulting 1-hr Moisture Content Correction (%) to the Reference Fuel Moisture (%)

Night Time Estimates of 1-hr Fuel Moisture

Published Reference Fuel Moisture and Correction Tables for Night Time Conditions are not included here based on recommendation from Pat Andrews at the Missoula Fire Lab. She recommends:

- Estimate Dry Bulb Temperature and RH for the location of interest
- Use Table A (above) to estimate the Reference Fuel Moisture
- Use the appropriate 1-hr Moisture Content Correction Table based on the time of the year
- Obtain the correction for 0800, shaded conditions, and appropriate aspect from that table and add it to the Reference Fuel Moisture to estimate 1-hr moisture content for night time conditions.

Table A. Reference Fuel Moisture

Dry Bulb Temp (°F)	Relative Humidity (%)																				
	0 to 4	5 to 9	10 to 14	15 to 19	20 to 24	25 to 29	30 to 34	35 to 39	40 to 44	45 to 49	50 to 54	55 to 59	60 to 64	65 to 69	70 to 74	75 to 79	80 to 84	85 to 89	90 to 94	95 to 99	100
10-29	1	2	2	3	4	5	5	6	7	8	8	8	9	9	10	11	12	12	13	13	14
30-49	1	2	2	3	4	5	5	6	7	7	7	8	9	9	10	10	11	12	13	13	13
50-69	1	2	2	3	4	5	5	6	6	7	7	8	8	9	9	10	11	12	12	12	13
70-89	1	1	2	2	3	4	5	5	6	7	7	8	8	8	9	10	10	11	12	12	13
90-109	1	1	2	2	3	4	4	5	6	7	7	8	8	8	9	10	10	11	12	12	13
109+	1	1	2	2	3	4	4	5	6	7	7	8	8	8	9	10	10	11	12	12	12

Table B. 1-hr Fuel Moisture Corrections, May-June-July

		Unshaded – Less than 50% shading of surface fuels																	
Aspect	Slope	0800-0959			1000-1159			1200-1359			1400-1559			1600-1759			1800-1959		
		B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A
N	0-30	2	3	4	1	1	1	0	0	1	0	0	1	1	1	1	2	3	4
	31%	3	4	4	1	2	2	1	1	2	1	1	2	1	2	2	3	4	4
E	0-30	2	2	3	1	1	1	0	0	1	0	0	1	1	1	2	3	4	4
	31%	1	2	2	0	0	1	0	0	1	1	1	2	2	3	4	4	5	6
S	0-30	2	3	3	1	1	1	0	0	1	0	0	1	1	1	1	2	3	3
	31%	2	3	3	1	1	2	0	1	1	0	1	1	1	1	2	2	3	3
W	0-30	2	3	4	1	1	2	0	0	1	0	0	1	0	1	1	2	3	3
	31%	4	5	6	2	3	4	1	1	2	0	0	1	0	0	1	1	2	2
		Shaded – 50 % or more shading of surface fuels due to canopy and/or cloud cover																	
N	All	4	5*	5	3	4	5	3	3	4	3	3	4	3	4	5	4	5	5
E	All	4	4*	5	3	4	5	3	3	4	3	4	4	3	4	5	4	5	6
S	All	4	4*	5	3	4	5	3	3	4	3	3	4	3	4	5	4	5	5
W	All	4	5*	6	3	4	5	3	3	4	3	3	4	3	4	5	4	4	5

Table C. 1-hr Fuel Moisture Corrections, Feb-Mar-Apr & Aug-Sep-Oct

		Unshaded – Less than 50% shading of surface fuels																	
Aspect	Slope	0800-0959			1000-1159			1200-1359			1400-1559			1600-1759			1800-1959		
		B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A
N	0-30	3	4	5	1	2	3	1	1	2	1	1	2	1	2	3	3	4	5
	31%	3	4	5	3	3	4	2	3	4	2	3	4	3	3	4	3	4	5
E	0-30	3	4	5	1	2	3	1	1	1	1	1	2	1	2	4	3	4	5
	31%	3	3	4	1	1	1	1	1	1	1	2	3	3	4	5	4	5	6
S	0-30	3	4	5	1	2	2	1	1	1	1	1	1	1	2	3	3	4	5
	31%	3	4	5	1	2	2	0	1	1	0	1	1	1	2	2	3	4	5
W	0-30	3	4	5	1	2	3	1	1	1	1	1	1	1	2	3	3	4	5
	31%	4	5	6	3	4	5	1	2	3	1	1	1	1	1	1	3	3	4
		Shaded – 50 % or more shading of surface fuels due to canopy and/or cloud cover																	
N	All	4	5*	6	4	5	5	3	4	5	3	4	5	4	5	5	4	5	6
E	All	4	5*	6	3	4	5	3	4	5	3	4	5	4	5	6	4	5	6
S	All	4	5*	6	3	4	5	3	4	5	3	4	5	3	4	5	4	5	6
W	All	4	5*	6	4	5	6	3	4	5	3	4	5	3	4	5	4	5	6

Table D. 1-hr Fuel Moisture Corrections, Nov-Dec-Jan

Unshaded – Less than 50% shading of surface fuels																			
Aspect	Slope	0800-0959 (+ night)			1000-1159			1200-1359			1400-1559			1600-1759			1800-1959		
		B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A
N	0-30	4	5	6	3	4	5	2	3	4	2	3	4	3	4	5	4	5	6
	31%	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
E	0-30	4	5	6	3	4	4	2	3	3	2	3	3	3	4	5	4	5	6
	31%	4	5	6	2	3	4	2	2	3	3	4	4	4	5	6	4	5	6
S	0-30	4	5	6	3	4	5	2	3	3	2	2	3	3	4	4	4	5	6
	31%	4	5	6	2	3	3	1	1	2	1	1	2	2	3	3	4	5	6
W	0-30	4	5	6	3	4	5	2	3	3	2	3	3	3	4	4	4	5	6
	31%	4	5	6	4	5	6	3	4	4	2	2	3	2	3	4	4	5	6
Shaded – 50 % or more shading of surface fuels due to canopy and/or cloud cover																			
N	All	4	5*	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
E	All	4	5*	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
S	All	4	5*	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
W	All	4	5*	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6

3.1.3 10hr, 100-hr and 1000-hr Fuel Moisture Content

10-hr and 100-hr Fuel Moisture may be estimated in the following ways and applied along with the Fosberg fuel moistures in surface fire behavior predictions. 1000-hr fuel moisture is not usually needed for fire behavior calculations.

- ***After estimating 1-hr moisture content***, 10-hr and 100-hr fuel moisture content can be estimated by adding incremental amounts (e.g. adding 1-2% for 10-hr and 2-4% for 100-hr).
- ***Using a local RAWS station*** or the Geographic Area's Predictive Service summaries, 78/88 NFDRS moisture content estimates or forecast values that utilize the Fosberg Model may be available for each of these fuel categories.
- ***The National Fuel Moisture Database*** may have sampling locations near your setting that have estimates for these fuel moistures (http://www.wfas.net/index.php/national-fuel-moisture-database-moisture-drought-103).

In NFDRS, if danger rating calculations are suspended in the dormant season, default dormant fuel moistures are provided for 100-hr (10%-25%) and 1000-hr (15%-30%) fuel moistures when calculations are restarted in the spring. Default values are established with climate class designation for the location.

3.1.4 Fuel Moisture Conditioning in US Spatial Fire Growth Models

Spatial analyses in WFDSS, FARSITE and FLAMMAP use historic and forecast weather to estimate current and future fuel moistures. At this writing in 2017, initial dead fuel moistures in deterministic analyses default to estimates from the Fosberg model while conditioning weather uses the Nelson model to adjust 1-hr and 10-hr fuel moisture content over 1 to several days. **Use 7 days or less**.

FSPro draws its fuel moistures in the ERC table from the NFDRS system and fuel model that produces its ERC distribution. As of this writing in 2017, it uses 78 Fuel Model G and the Fosberg model for all dead fuel moistures.

3.2 Probability of Ignition

With concepts developed by Schroeder (1969) and adapted by Andrews, probability of ignition is estimated from:

- current temperature,
- shading from either forest canopy or cloud cover,
- 1-hr fuel moisture content.

	DB Temp (°F)	1-hr Moisture Content (%)															
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
0-10% shading	110+	100	100	90	80	70	60	50	40	40	30	30	30	20	20	20	10
	100-109	100	90	80	70	60	60	50	40	40	30	30	20	20	20	10	10
	90-99	100	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10
	80-89	100	90	80	70	60	50	40	40	30	30	20	20	20	20	10	10
	70-79	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	60-69	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10	10
	50-59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	40-49	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	30-39	90	70	60	60	50	40	40	30	30	20	20	20	10	10	10	10
10-50% shading	110+	100	100	80	70	60	60	50	40	40	30	30	20	20	20	20	10
	100-109	100	90	80	70	60	50	50	40	40	30	30	20	20	20	10	10
	90-99	100	90	80	70	60	50	40	40	30	30	30	20	20	20	10	10
	80-89	100	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10
	70-79	100	80	70	60	50	50	40	40	30	30	20	20	20	10	10	10
	60-69	90	80	70	60	50	50	40	30	30	20	20	20	20	10	10	10
	50-59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	40-49	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	30-39	80	70	60	50	50	40	30	30	20	20	20	10	10	10	10	10
60-90% shading	110+	100	90	80	70	60	50	50	40	40	30	30	20	20	20	10	10
	100-109	100	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10
	90-99	100	80	80	70	60	50	40	40	30	30	20	20	20	10	10	10
	80-89	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	70-79	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10	10
	60-69	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	50-59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	40-49	90	70	60	50	50	40	30	30	30	20	20	20	10	10	10	10
	30-39	80	70	60	50	50	40	30	30	20	20	20	10	10	10	10	10
100% shading	110+	100	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10
	100-109	100	90	80	70	60	50	40	40	30	30	20	20	20	20	10	10
	90-99	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	80-89	90	80	70	60	60	50	40	30	30	30	20	20	20	10	10	10
	70-79	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	60-69	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	50-59	90	70	60	60	50	40	40	30	30	20	20	20	10	10	10	10
	40-49	80	70	60	50	50	40	30	30	20	20	20	10	10	10	10	10
	30-39	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10	10

3.3 Live Fuel Moisture Content

3.3.1 Concepts and Methods

This table (Rothermel, 1983) suggests the fuel moisture associated with the phenology or stages of plant development through a year that includes dormancy.

Moisture Content (%)	Stage of Vegetative Development
300%	Fresh foliage, annuals developing early in the growing cycle.
200%	Maturing foliage, still developing, with full turgor.
100%	Mature foliage, new growth complete and comparable to older perennial foliage.
50%	Entering dormancy, coloration starting, some leaves may have dropped from stem.
30%	Completely cured, treat as dead fuel.

Trends in live fuel moisture vary widely, but NFDRS and US Fire Behavior Prediction methods categorize them as herbaceous and woody fuel moistures. NFDRS models trend live fuel moisture according to these stages of plant development:

- During ***dormancy***, all three models estimate herbaceous fuel moisture as if they were dead fine fuels. Minimum woody fuel moisture estimates vary, when dormant, according to the established Climate Class for the weather observing location.
- ***Greenup/Green*** occurs in spring and early summer, when live fuel moistures trend from dormant minimums up to 250% under most favorable conditions
- ***Transition*** describes the process of progressive curing due to dry weather and soil conditions prior to frost and freezing conditions.
- ***Freeze/Frozen*** conditions lead to rapid curing of live fuels into a dormant state at the end of the season if they haven't already been fully cured in transition.

1978 NFDRS expects the user to identify a greenup date, after which live fuel moistures increase to maximum levels over a fixed number of days established by the climate class designation. After that, live fuel moistures transition trends follow 1000hr (and x1000h) trends until fully cured or freeze/frozen conditions are selected.

1988 NFDRS replaced the greenup and transition trends with user selected designations of Season and greenness level for herbaceous and woody fuels.

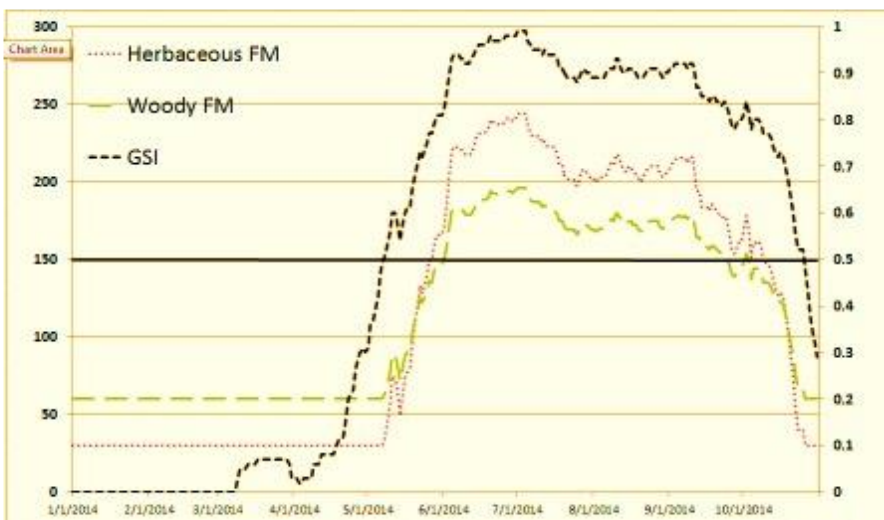
2016 NFDRS uses a weather based index of plant development, called the Growing Season Index (GSI), to automate the process. It identifies when greenup begins, how fast it progresses, the maximum live fuel moisture, transition curing, and when freeze/frozen dormant conditions occur.

3.3.2 Growing Season Index (GSI)/Live Fuel Index (LFI)

The Growing Season Index (Jolly et al, 2005) is a simple metric of plant physiological limits to photosynthesis. It is highly correlated to the seasonal changes in both the amount and activity of plant canopies. It predicts the green-up and senescence of live fuels and the influence of water stress events on vegetation. GSI is calculated as a function of the three indicators of important weather factors that regulate plant functions. These indicators are combined into a single indicator that integrates the limiting effects of temperature, water and light deficiencies. More information can be found at https://www.wfas.net.

- **Minimum temperature:** Many of the biochemical processes of plants are sensitive to low temperatures. Although ambient air temperatures certainly influence growth, constraints on phenology appear to be more closely related to restrictions on water uptake by roots when soil temperatures are suboptimal and many field studies show variable ecosystem responses over a range of minimum temperatures.
- **Vapor Pressure Deficit (VPD):** Water stress causes partial to complete stomatal closure, reduces leaf development rate, induces the shedding of leaves, and slows or halts cell division. Although models are available to calculate a soil water balance, they require knowledge of rooting depth, soil texture, latent heat losses, and precipitation. As a surrogate, we selected an index of the evaporative demand, the vapor pressure deficit (VPD) of the atmosphere.
- **Photoperiod or Daylength:** Photoperiod provides a plant with a reliable annual climatic cue because it does not vary from year to year at a given location. We assume that photoperiod provides the outer envelope within which other climatic controls may dictate foliar development. Studies have shown that photoperiod is important to both leaf flush and leaf senescence throughout the world.

Example 2014 seasonal values of the GSI and Live Fuel Moisture. Watford North Dakota (from wfas.net)



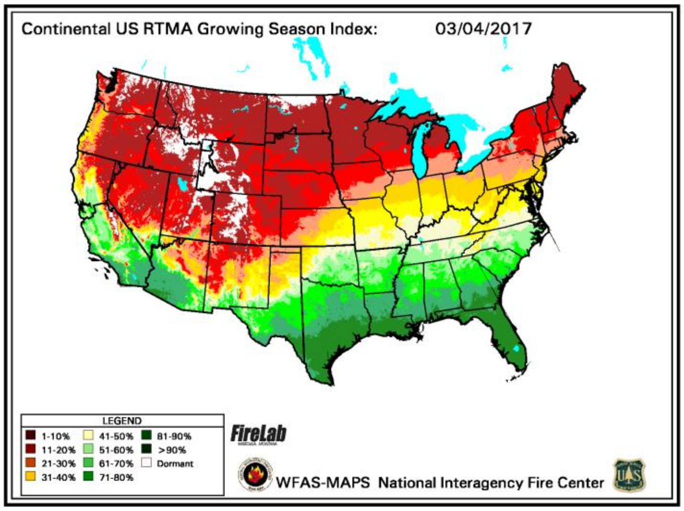
Upper and lower limits of the indicator functions used to calculate the Growing Season.

Input Variable	Unconstrained (=1)	Completely limiting (=0)
Minimum Temperature	5°C /41° F	-2°C /28° F
Vapor Pressure Deficit (Pascals)	900 Pascals	4100 Pascals
Photoperiod (Daylength)	11 hours	10 hours

Example values of the GSI, their interpretation and effect on NFDRS Live Fuel Moistures.

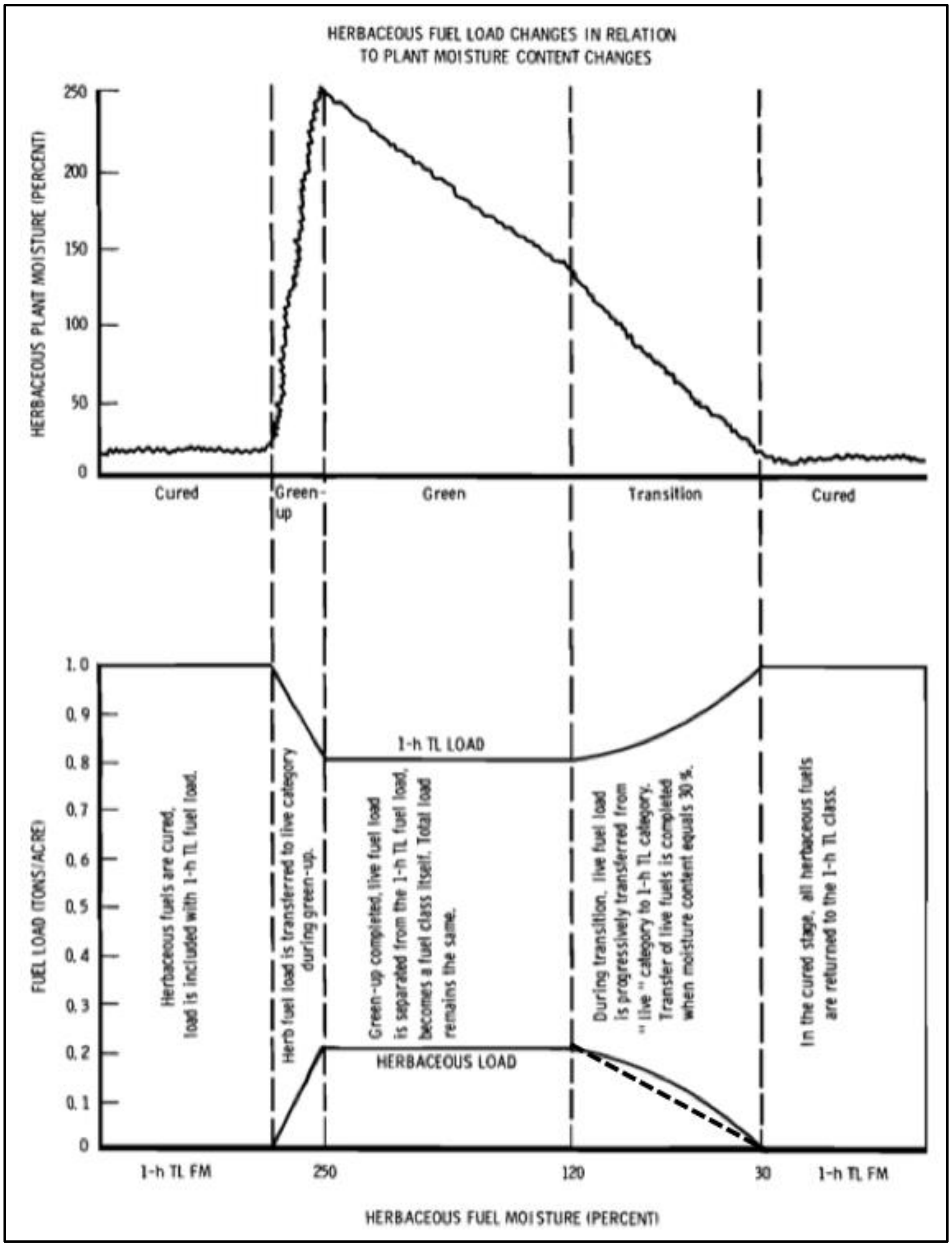
GSI Value	Classification / Interpretation
GSI Increasing	
0 to 0.5	Pre-greenup; dormancy. Herbaceous fuels at 30%, Woody shrubs at dormant values (50% to 80%).
> 0.50	Green-up; Live fuel moisture increases linearly with GSI from dormant values.
0.5 to 1.0	Closed green plant canopies. Live fuel moisture fluctuates with GSI. If GSI reaches 1.0 live moistures are limited to 250% for herbaceous fuels and 200% for live woody fuels.
GSI Decreasing	
1.0 to 0.5	Live fuel moisture fluctuates with GSI.
< 0.5	Leaf senescence.
Below 0.5	Cured herbaceous and shrub dormancy. Herbaceous fuels at 30%, Woody shrubs at dormant values (50% to 80%).

The data and processing of the GSI, and the dependent live fuel moistures, make gridded map depictions possible and automated processing a reality.



3.3.3 Herbaceous Fuel Moisture Content

As shown in this graph (Burgan, 1979), herbaceous fuel moisture influences both the flammability of living herbaceous vegetation and the transfer of living herbaceous fuel loads from and to dead fine fuels. The dashed line with the herbaceous load trend shows the trend for dynamic fire behavior fuel models.



- Herbaceous fuel moistures vary between 30% at dormancy and 250% at peak greenup.
- Herbaceous loads are transferred to and from dead fine fuel loads based on fuel moisture. At 30%, all load is dead. At 120% all load is live.
- In 2016 NFDRS, herbaceous FM is at 30% when GSI is 0.5 or less and at 250% when GSI is at 1.0. HFM trends match GSI between 0.5 and 1.0.

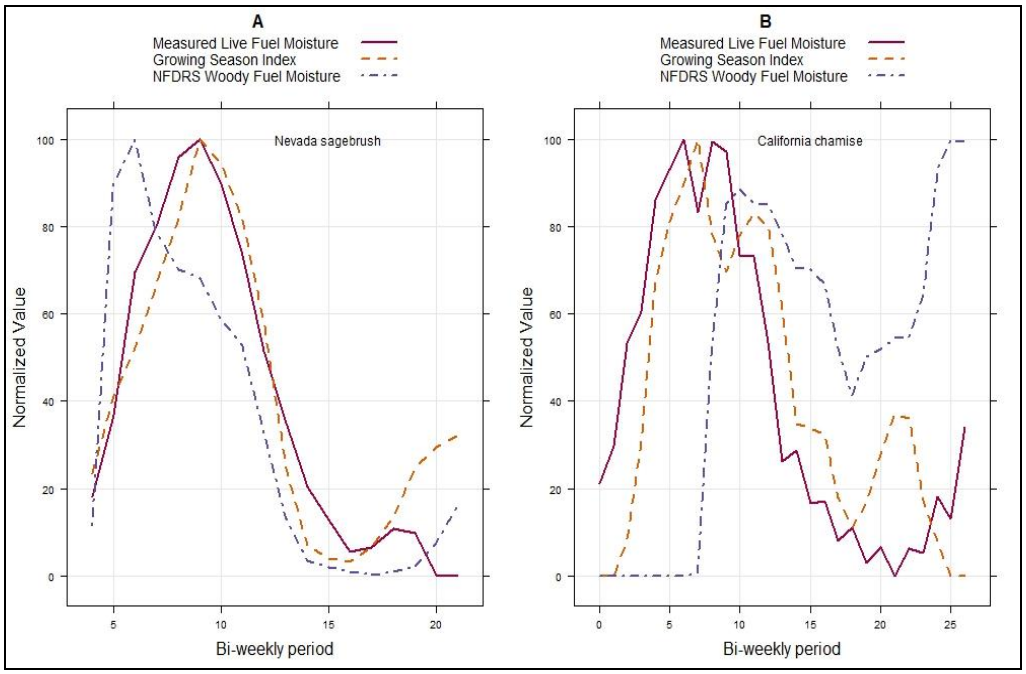
3.3.4 Woody Fuel Moisture (WFM) Content

Though similar in trend to herbaceous fuel moisture content, woody fuel moisture content ranges with less extremes:

- Dormant defaults range from 50% in climate class 1 to 80% in climate class 4
- Peak green conditions are represented by fuel moisture of 200%
- In 2016 NFDRS, min WFM is set at GSI of 0.5 or less, at 200% at GSI of 1.0, and trends with GSI between those levels.

There is no fuel load transfer between live and dead fuels based on woody fuel moisture.

This graphic shows the agreement between the Growing Season Index (GSI) trend and measured woody fuel moisture for Nevada Sagebrush and California Chamise, two very important fire landscapes. Note also how they differ from the 1978 NFDRS woody fuel moisture trend that was based on the 1000hr fuel moisture trend.



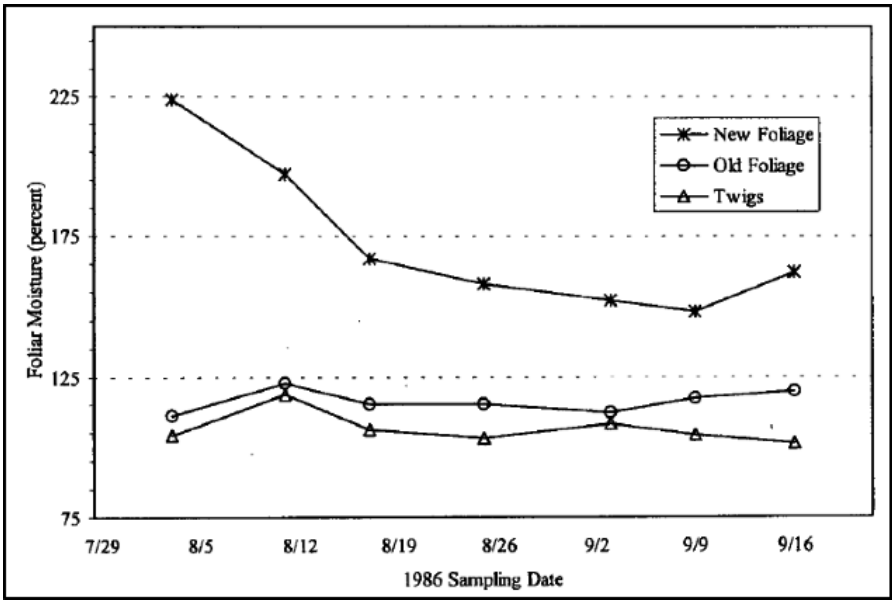
3.3.5 Foliar Moisture Content

Foliar Moisture Content is defined (in the BehavePlus Variable) help as the moisture content of the conifer needles in tree crowns. It is used along with surface fire intensity and crown base height as input to the crown fire initiation model (described in section 5). Further, it is generally measured using only mature conifer needles (at least one-year old).

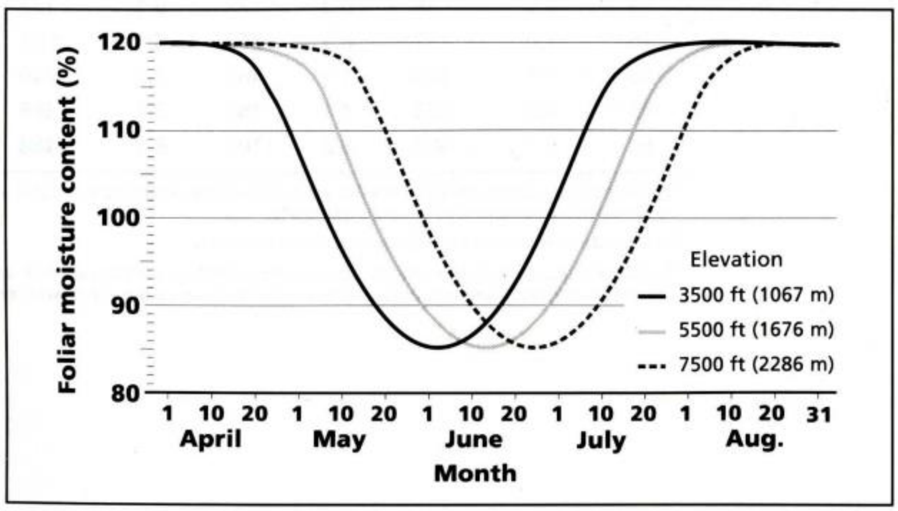
In some cases, evergreen hardwoods and deciduous species with resinous leaves will carry crown fire. Estimates of foliar moisture should reflect flammability of these crown fuels.

BehavePlus allows a range of 30%-300% as with other live fuels, but WFDSS allows only a range of 70% to 130. Default value is typically 100%.

The example plot below, for Abies lasiocarpa or Subalpine Fir, compares moisture content for new and old foliage. (Agee, et al 2002).



As shown in this graph, there is a measurable ***"Spring Dip"*** in measured foliar moisture content of mature needles associated with the emergence of new growth, at least among northern conifers. (Hirsch, 1996 and Jolly et.al., 2014)



3.4 Fuel Moisture Sampling

Fuel moisture sampling can provide useful insight to current conditions if it is done consistently throughout each fire season. Results from sampling efforts around the United States are stored in the National Fuel Moisture Database:

http://wfas.net/index.php/national-fuel-moisture-database-moisture-drought-103

Results for sampling history of both live and dead fuels are available for locations around the United States.

3.4.1 Fuel Moisture Sampling Procedures

General Guidelines

- Record site name, date, time, observer name, observed weather, general site description
- DO NOT collect samples if water drops or dew are present on samples
- Keep samples in a cool and dry location
- Seal containers with tape that will not leave residue

Live Fuel Samples

- Only collect foliage (needles) and very small twigs remove flowers, seeds, nuts, or berries
- Pack containers loosely to avoid spillage but ensure container is full
- Include stems of herbaceous plants
- Replace lid on container immediately after collecting sample

Dead Fuel Samples

- Samples should not be attached to live trees or shrubs
- Avoid decayed samples that crumble or splinter when rubbed
- Collect samples from several different plants
- Ensure container is full or about 20 grams
- Do not collect buried samples
- Pick samples of different size within the time lag class
- Recently fallen material should be avoided
- Remove all lichen, moss, and very loose bark from sample

Duff and Soil Samples

- Remove all soil and live tree or plant roots from sample
- Avoid any soil particles in duff samples and vice versa

Litter Samples

- Collect only un-compacted dry litter from both sunny and shady areas

Handling and Measuring Samples

- Preheat drying oven between 60°C (140°F) – 100°C (212°F). Be sure to note temp used.
- Place sample cans with closed lids on scale and record "wet" weights
- Remove lid just prior to placing in oven. If material is lost, re-weigh sample
- Dry sample for 24 hours (very wet samples 48 hours)
- Replace Lids immediately after sample is removed from oven and weigh
- Calculate fuel moisture using worksheet provided here:

$$\%\ Moisture\ Content = \frac{wet\ weight\ of\ sample - dry\ weight\ of\ sample}{dry\ weight\ of\ sample - container\ tare\ weight}\ X\ 100$$

Gross Weight		C. Container Weight	D. Water Weight **(D = A – B)**	E. Dry Weight **(E = B – C)**	F. % Moisture **F=(D/E) X 100**
A. Wet Wt	B. Dry Wt.				

3.5 Normalized Difference Vegetation Index (NDVI)

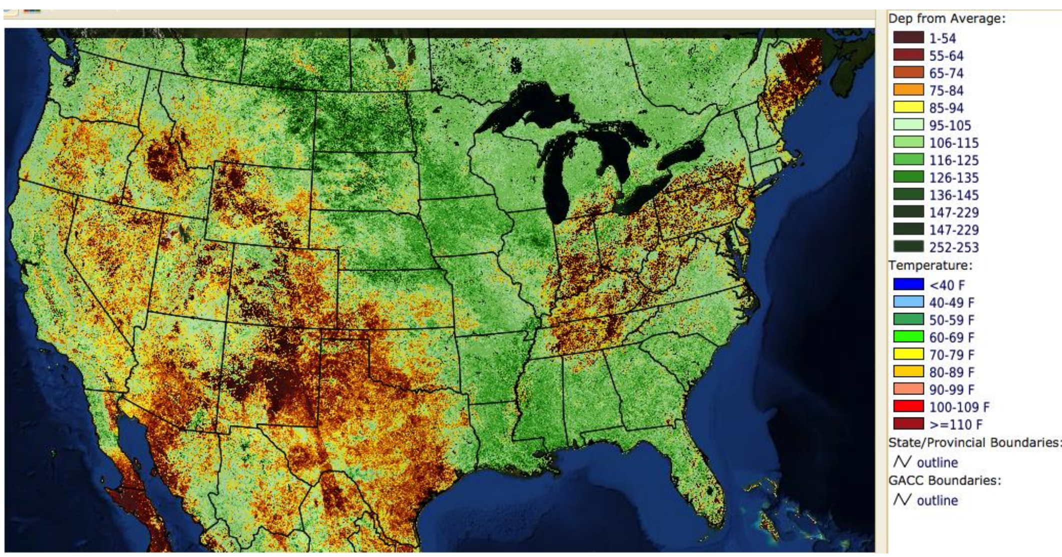
These images, derived from a satellite sensor, have been produced weekly since 1989, producing a historical record of vegetation phenology that can be used to characterize current vegetation "greenness". They can be used to cross-reference with drought assessments and other characterizations of plant development, moisture stress and curing. Cloud cover can have a significant impact on image quality in portions of the image.

While not an estimate of live fuel moisture, spatial distribution of NDVI estimates and its climatological derivatives can provide important insight to past and current vegetative state as well as overall landscape flammability during the growing season.

There are several depictions that allow you to evaluate the current NDVI status:

- **Normalized Difference Vegetation Index (ND)** is the current derived value from which all the other climatological depictions are derived.
- **Departure from Average Greenness (DA)** portrays the absolute difference between current value and the historic average greenness for the corresponding week of the year based on all years 1989-last year.
- **Relative Greenness (RG)** portrays how green the vegetation is compared to how green it has been over the historical reference period (1989-last year). Because each pixel is normalized to its own historical range, all areas (dry to wet) can appear fully green at some time during the growing season.
- **Visual Greenness (VG)** portrays vegetation greenness compared to a very green reference such as an alfalfa field or a golf course. The resulting image is like what you would expect to see from the air. Normally dry areas will never show as green as normally wetter areas.

This image of ***Departure from Average Greenness*** is for September 12, 2011.



Wildland Fire Assessment System (WFAS) AVHRR NDVI Greenness Reference is the comprehensive source of images, data archives, and methods for handling.

3.6 NASA SPoRT Land Information System (SPoRT LIS)

The NASA Short-term Prediction Research and Transition (SPoRT) Center has developed a Real-Time Land Information System (LIS), using satellite-derived datasets, ground-based observations, and model reanalysis to inform weather models with influences from the land surface.

URL: https://weather.msfc.nasa.gov/sport/case_studies/lis_CONUS.html

Products are updated on a daily basis and include:

- Volumetric Soil Moisture represents actual moisture in a soil column
- Relative Soil Moisture represents the soil moisture for a given soil column on a relative scale between soil saturation and wilting levels
- Column-Integrated Relative Soil Moisture combines 4 levels down to 200cm.
- Green Vegetation Fraction (current and Trends) from VIIRS
- Land surface temperature and Heat Flux

Soil Moisture products evaluate conditions at five levels:

- 0-10 cm (relates most directly to the FWI Duff Moisture Code, or DMC)
- 10-40 cm (relates most directly to the FWI Drought Code, or DC)
- 40-100 cm
- 100-200 cm
- 0-200 cm Integrated Column

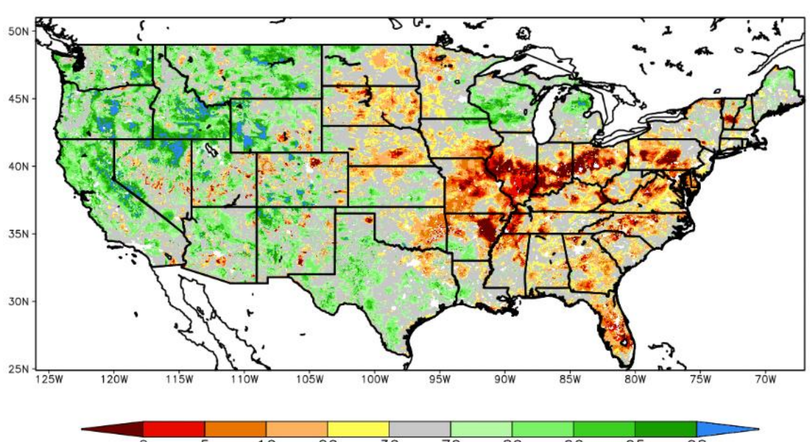
Available at 3km resolutions for the Continental US (CONUS), analysts should consider using the:

Column-Integrated Relative Soil Moisture products to assess current drought levels and changes over 1 week, 2 weeks, 1 month, 3 months, 6 months, and 1 year.

Green Vegetation Fraction products that are updated daily in lieu of NDVI that are updated on only a weekly basis. Current conditions are augmented by 1-month, 2-month, 3-month, 4-month, and 1-year change products.

Relative Soil Moisture products that may be correlated to fuel moisture contents applied in fire effects and fire spread models. A 0-10 cm 1-day change product provides an assessment of rainfall effects on the top soil layer that relates to fuel moisture in carrier fuels.

SPoRT—LIS 0–2 m RSM percentile valid 18 Apr 2017



3.7 References

Useful Online Resources

- National Fuel Moisture Database
- NDVI Greenness Resources
- 1-hr Fuel Moisture (SimpleFFMC – Nelson Model)

Publications

Agee, James K, Wright, Clinton S. Williamson, Nathan, and Huff, Mark H.; Foliar Moisture Content of Pacific Northwest Vegetation and its Relation to Wildland Fire Behavior; 2002; Forest Ecology and Management; 167: 57-66.

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Hirsch, Kelvin G.; Canadian Forest Fire Behavior Prediction (FBP) System: User's Guide; 1996; Canadian Forest Service Special Report 7; 122p.

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Nelson R.M., Jr. 2000. Prediction of diurnal change in 10-h fuel stick moisture content. Canadian Journal of Forest Research 30(7):1071–1087.

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Rothermel, Richard C. 1983. How to predict the spread and intensity of forest and range fires. Gen. Tech. Rep. INT-143. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 161 p.

Schlobohm, P. and Brain, J. 2002. Gaining an Understanding of the National Fire Danger Rating System. National Wildfire Coordinating Group. PMS 932/NFES 2665.

Schroeder, Mark J. 1969. Ignition probability. U.S. Forest Service Office Report 2106-1. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. 27 p.

4. Mapping

4.1 Map and Field Measurements

Scale	Rep. fraction	Map (in/mi)	Map (in/ch)	Feet per map inch
1:253,440	253.44	0.25	0.0031	21120
1:126,720	126.72	0.50	0.0063	10560
1:63,360	63.36	1	0.0125	5280
1:62,500	62.5	1.01	0.0127	5188
1:31,680	31.68	2	0.025	2640
1:24,000	24	2.64	0.033	2000
1:21,120	21.12	3	0.0375	1760
1:15,840	15.84	4	0.05	1320
1:7,920	7.92	8	0.1	660

4.1.1 Map Scale & Map Distance

The map scale is printed in the map legend. It is given as a ratio of inches on the map corresponding to inches, feet, or miles on the ground. For example, a map scale indicating a ratio of 1: 24,000 (in/in), means that for every 1 inch on the map, 24,000 inches have been covered on the ground. Ground distances on maps are usually given in feet or miles.

Firefighter Math Map Scale; Firefighter Math Spread/Map Distance

4.1.2 Slope Estimation

Standard LANDFIRE slope themes are represented in units of degrees (°). Many locally produced landscapes over the year's stored slopes in percent (%). It is much easier to estimate slope in %, estimating the elevation change and the horizontal distance and calculating the ratio. BehavePlus, and BEHAVE tools before that, default to slope input in %.

Firefighter Math Slope Percent and Slope Angle

To convert from slope in degrees (°) to slope in percent (%), a scientific calculator is needed.

- Enter the slope in degrees
- Press the Tangent button
- Multiply the result by 100 to get slope in %

Slope (Degrees)	Slope (Percent)
10º	17.6 %
20º	36.4 %
30º	57.7 %
40º	83.9 %
45º	100 %
50º	119.2 %
60º	173.2 %
70º	274.7 %
80º	567.1 %
90º	∞

4.1.3 Unit Conversions

Online and downloadable apps are available from Apple (OSX & IOS), Google Play (Android), and MS Windows for making unit conversions for distance, temperature, area, volume, weight, time, energy and other items.

Firefighter Math Conversions reference provides several tables and conversion factors for the user.

4.1.4 Average Latitude for Each State

Alabama	33
Alaska	65
Arizona	35
Arkansas	35
California	38
Colorado	39
Connecticut	41
Delaware	39
Florida	28
Georgia	33
Hawaii	21
Idaho	45
Illinois	40
Indiana	40
Iowa	42
Kansas	39
Kentucky	37

Louisiana	31
Maine	45
Maryland	39
Massachusetts	42
Michigan	43
Minnesota	46
Mississippi	32
Missouri	39
Montana	47
Nebraska	41
Nevada	39
New	44
New Jersey	40
New Mexico	34
New York	43
North Carolina	35

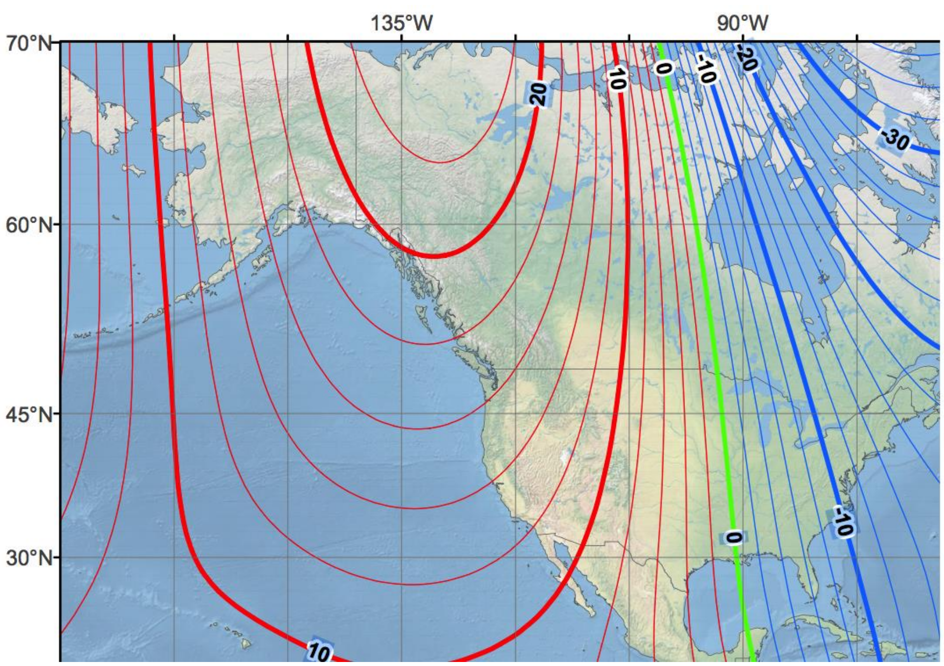
North Dakota	47
Ohio	40
Oklahoma	35
Oregon	44
Pennsylvania	41
Rhode Island	41
South	34
South	44
Tennessee	36
Texas	32
Utah	39
Vermont	44
Virginia	37
Washington	47
West Virginia	38
Wisconsin	44
Wyoming	43

4.1.5 Declination

Global Reference: https://maps.ngdc.noaa.gov/viewers/historical_declination/

Calculator: https://www.ngdc.noaa.gov/geomag-web/#declination

US/UK World Magnetic Model - Epoch 2015.0 Main Field Declination (D)
*(East Declination in **Red**, West in **Blue**; subtract from true compass reading)*



4.2 Global Positioning System (GPS) Procedures

4.2.1 Set up before going to the field

- Make sure ***fresh batteries*** are loaded and extra sets available.
- Transfer ***background map***s for the area using MapSource (if available).
- Turn unit on to initialize and ***acquire satellites*** ahead of time if you are in a new area or haven't used the unit in at least a week. This may take as long as 20 minutes in the open, away from buildings, canopy and obstructions.
- Download and ***clear old waypoints and tracks*** from memory.
- ***Turn off active track log***. Set it to the preferred Collection method (Time is best) and an appropriate logging rate for the data collection. 5 seconds works for most walking collection. Keep in mind the total storage of the GPS.
- Ensure Simulator Mode is not ON when collecting data.
- Set unit time zone and date (Ensure Daylight Savings Time if needed).
- Check Interface Protocol is set properly.
- Set the ***Coordinate System*** (UTM or LAT/LONG) & Datum to ensure compatibility with written coordinates you may need to navigate to or Map.
- ***Set Heading*** to magnetic or true. If "true", ensure same declination is used.

4.2.2 Field – GPS Data Collection

- Hold GPS antenna away from body with antenna up. Better yet, hold at, or above the head. Purchase an external antenna to free hands if needed or for better reception in vehicles.
- ***Mark (save) waypoints*** **for point locations at beginning and ending of track log collections**. Writing down a position is just backup.
- Most GPS units will collect data no matter what the GPS quality is. It's up to you to monitor the GPS Satellite Page for anomalies and accuracy.
- Collect when "3D GPS" is shown. Do not collect data in 2D unless necessary.

4.2.3 Waypoints

- ***Collect all waypoints in Averaged Position*** mode if you are standing still (when possible and if your receiver has that capability). Minimum of 10 positions, maximum of 20 minutes. Somewhere in between is enough to generate a quality position in most cases.
- Collect an instantaneous waypoint only when moving or in a hurry (or if using the eTrex line).
- Edit default waypoint numbers to letters or words that are more descriptive or make good field notes to ensure you remember what features are represented by which numbers.

4.2.4 Track logs

- Use "Stop when Full" or "Fill" Record Mode rather than wrap to prevent overwriting track log points when Active Track log becomes full.
- Turn on Active Track log at start location and immediately begin moving.
- ***Stop Active Track log*** when movement is stopped or mission is finished.
- Always Stop Active Track just shy of starting point when collecting an area (polygon). Overlapping makes conversion to GIS more challenging.
- Use caution when saving an Active Track log. Garmin will generalize active track to save space, thereby degrading data.

4.3 Using Geographic Information Systems (GIS)

4.3.1 Map Datum

Some common datum, or Global Coordinate Systems (GCS), used in North America include:

- ***North American Datum of 1927 (NAD27):*** Local datum well suited to the United States, Canada, Mexico, and the Caribbean. Uses the Clarke 1866 spheroid.
- ***North American Datum of 1983 (NAD83):*** An earth-centered datum that corrects NAD27 coordinates based on both earth and satellite measurements. Uses the GRS 1980 spheroid. Coordinates are very like WGS84 coordinates and can be used interchangeably with them.
- ***World Geodetic System of 1984 (WGS84):*** Earth-centered datum common for datasets with a global extent. Uses the WGS 1984 spheroid. This is the datum that GPS coordinates are based on.

Geographic transformations between different Datum

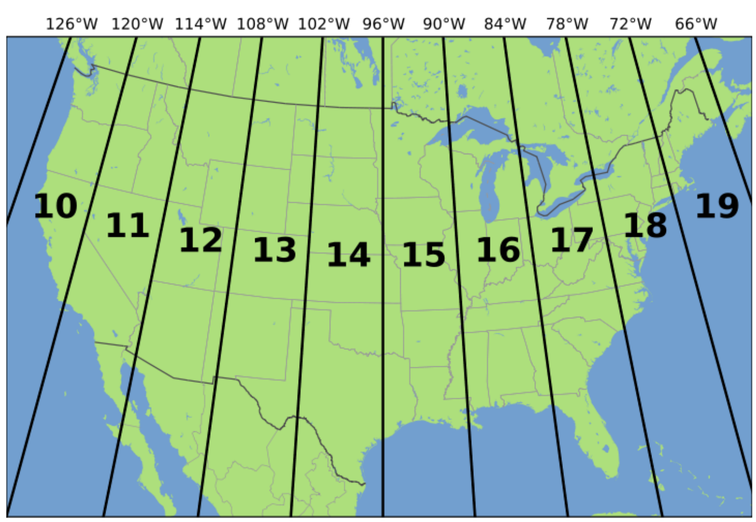
ArcGIS gives us a warning if we attempt to add data to our map that have a different GCS, or datum. For example, if we have one layer depicting the 40 fire behavior fuel models. As with projection on-the-fly, the data frame's GCS defaults to that of the first layer added to the map, which is North American 1983. If we then try to add a fire perimeter shapefile with the WGS 1984 geographic coordinate system, we get a warning that a geographic transformation may be necessary.

A geographic transformation, sometimes referred to as a datum transformation, is a set of mathematical formulas for converting coordinates from one datum to another. At this point, you may specify the transformation by clicking the transformations box in the warning dialog box. *In most cases, the transformation at the top of the list will be the best choice.*

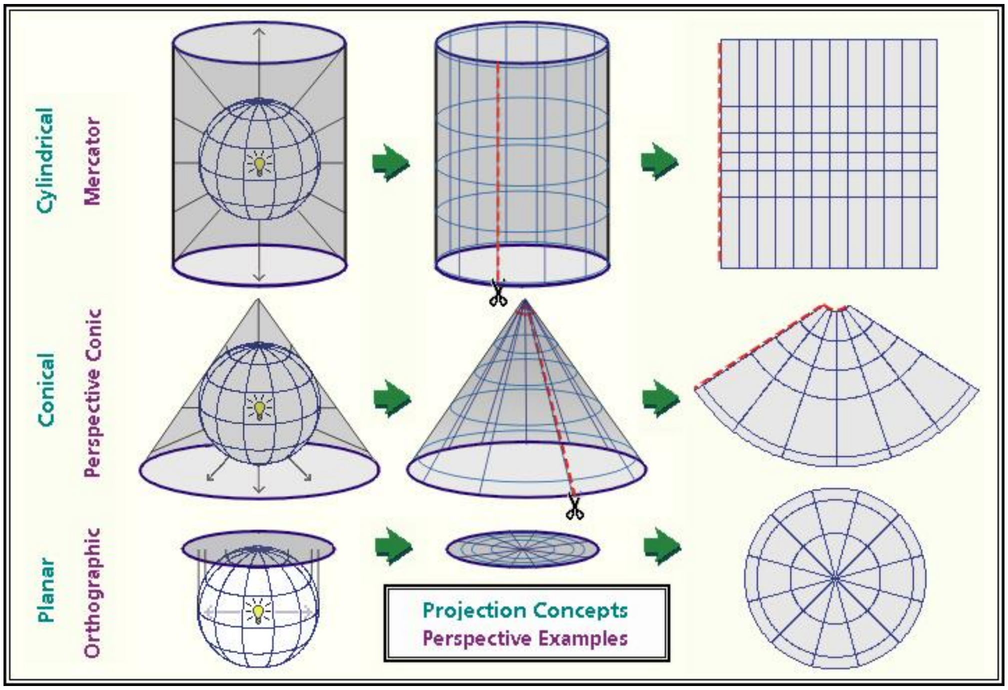
4.3.2 Map Projections & Coordinate Systems

A projected coordinate system (PCS) can reference the same geographic locations using a Cartesian system, which includes a uniform, linear unit of measure.

- ***Universal Transverse Mercator (UTM)*** divides the earth into 60 zones, each six degrees of latitude wide. Figure 9 below depicts a simplified view of the UTM zones covering conterminous United States.



- ***State Plane Coordinate Systems*** are a good example of a PCS being independent of its map projection. *Lambert Conformal Conic projections* are used for domains with greater east-west extent, *Transverse Mercator projections* are used for domains with greater north-south extent. Some use an oblique Mercator projection.



- ***LANDFIRE*** (http://www.landfire.gov) uses the Albers Equal Area Conic projection for national level data products because it is well suited for data with an east-west orientation at middle latitudes, such as the continental United States. Furthermore, because this is an equal area projection, all areas on the map are proportional to the same areas on the earth.

- ***WFDSS Custom Albers Projection*** is an Albers Equal Area Conic projection that is defined based upon the WFDSS incident spatial domain. In that sense, each incident and its associated fire behavior analyses will have a unique WFDSS Custom Albers projection, by using a custom projection for each incident, centered on that incident, reduces the distortion inherent in all projections in the area around the fire. Among other factors, the custom projection reduces the potential for errors in direction (wind direction, aspect, etc.) that could otherwise be introduced if a non-custom projection were used.

  Within the WFDSS incident, landscape (lcp) files created for fire behavior analyses are stored in its Custom Albers projection and can only be downloaded in that projection. Other fire behavior outputs can be downloaded in either the WFDSS Custom Albers projection or in a geographic coordinate system.

  The WFDSS Custom Albers projection is recognized by ArcGIS and datasets stored in a WFDSS Custom Albers projection can be used in ArcMap like any other dataset.

4.3.3 Re-projecting Shapefile or arcgrid in ArcGIS

If a shapefile or ascii grid will not display as an overlay on a landscape (lcp) in FARSITE or FLAMMAP, it cannot be used by those systems. It is most likely using a different coordinate system than the lcp does.

In this case, the file (feature/shapefile or raster/ascii grid) can be re-projected to the same coordinate system so it can be displayed onscreen and used in reference by the landscape editor in FARSITE.

1. Open a new ArcMap window and add the shapefile or raster file that is stored in the desired projection. By adding the shapefile (or grid) with the desired projection first, the coordinate system of the Data Frame will default to the desired projection.
2. Next, add the shapefile that is stored in the other projection.
3. If the ArcToolbox window is not already displayed, click on the ArcToolbox icon  to show the ArcToolbox window.
4. In the ArcToolbox window, click on the plus sign next to “Data Management Tools” to expand the selection. Next, click on the plus sign next to “Projections and Transformations” to expand the selection. Next, click on the plus sign next to “Feature” (for shapefiles or “Raster” (for grids) to expand the selection. Double-click on “Project” to open the tool.
5. In the Project window, under “Input Dataset or Feature Class,” select the shapefile/raster grid that is currently stored with the wrong projection. The Input Coordinate System should automatically default to its projection.” If none is displayed, that means that there is no prj file accompanying it. If the projection is known, it can be specified here.
6. Specify an output shapefile or raster grid under “Output Dataset or Feature Class.” Click on the  button next to “Output Coordinate System.” In the “Spatial Reference Properties” window that pops up, click on the “Import” button. Navigate to and select the shapefile that is stored in desired coordinate system. The new projection properties will load into the “Spatial Reference Properties” window. Click “OK” on the “Spatial Reference Properties” window.
7. Click “OK” in the “Project” window to create a new shapefile that is stored in the chosen UTM projection.

If the user discovers the feature or raster does not have a defined projection; one can be added by selecting “Define Projection”, found under “Projections and Transformations”

4.3.4 ArcGIS Web Services.

4.4 Digital Mapping Resources

4.4.1 Online Data Sources

In addition to these national sources, make sure to ask what local GIS resources may be available for your use.

NIFC Enterprise Geospatial Portal (EGP)
https://egp.nwcg.gov/egp/

FSGeodata Clearinghouse

https://data.fs.usda.gov/geodata/

USGS National Map

https://viewer.nationalmap.gov/launch/

LANDFIRE

https://landfire.gov/

4.4.2 Desktop Applications

ArcGIS for Personal Use

http://www.esri.com/software/arcgis/arcgis-for-personal-use

ArcGIS Explorer

http://www.esri.com/software/arcgis/explorer

QGIS-Free and Open Source

http://www.qgis.org/en/site/

GRASS GIS

(https://grass.osgeo.org/)

4.4.3 Google Earth Pro

Settings

Viewing 3D Terrain in Google Earth Pro requires selecting the terrain option from the bottom of the "layers" portion of the left side menu.

Resources

- ***Active Fire Mapping Bundle***
  https://fsapps.nwcg.gov/afm/data/kml/conus_latest_AFM_bundle.kml
- ***WFAS Fire Weather Observations/Forecasts***
  http://wfas.net/index.php/google-earth-map-data-weather-100
- ***NWS Data in KML Formats***
  http://www.nws.noaa.gov/gis/kmlpage.htm
- ***WFDSS Incident, Group, and Analysis Data***
  http://wfdss.usgs.gov
- ***Public Land Survey (PLSGE)***
  http://www.metzgerwillard.us/plss/plss.html
- ***USGS Topographic Maps***
  http://www.earthpoint.us/TopoMap.aspx

4.4.4 Mobile Applications

Collector for ArcGIS

URL: http://www.esri.com/products/collector-for-arcgis

Collector works on iOS, Android, and Windows 10 and allows user to collect and update information in the field, take maps and data offline and sync changes when connected, attribute data collection with easy-to-use map-driven forms, capture and share photos and videos

Avenza Maps and Pro Subscriptions

URL: https://www.avenzamaps.com/

Avenza Maps is GIS technology available on Apple, Android, and Windows devices for navigation, information collection, and sharing geographic information and knowledge. It displays geospatial PDF, GeoPDF® and GeoTIFF and interacts with the GPS on the device, allowing the user to record GPS tracks, add placemarks, and find places.

With ***Avenza Maps Pro***, users will be able to import and export shapefiles as well as all the current capabilities of the Avenza PDF Maps App in terms of data collection and editing but with Avenza Maps Pro, shapefiles are a supported import/export format. More features will be added, over time. It is a ***subscription service***, requiring registration of individual devices.

With the release of the Pro version, the current standard Avenza PDF Maps App will be changing, with the most significant change being that users may only access 3 maps at any one time on their device (unless the maps have all been obtained from the Avenza Map Store). It is strongly recommended that all users upgrade to the new Avenza Maps Pro version.

Avenza Maps Pro may be available under an enterprise license contract through the US Forest Service.

Other Products

- ***Gaia GPS and GaiaPro***

  Gaia GPS integrates the best topo maps, offline navigation tools, and planning features, seamlessly across phones, tablets, and gaiagps.com. GaiaPro spans Gaia GPS on iOS, Android, and gaiagps.com. ***GaiaPro*** is an upgrade to the standard application, including custom maps include premium satellite imagery, public land, and hunting zones, and tools including layered maps, area measurement, and printing.

- ***You Need a Map***

  URL: https://itunes.apple.com/us/app/you-need-a-map/id415545903

  A map that works in Apple IOS to provide cover of the US without a cell phone signal, showing not just roads but also terrain, streams, lakes and other landmarks.

- ***Theodolite***

  URL: https://itunes.apple.com/us/app/theodolite/id339393884?mt=8

5. Surface Fire Behavior

5.1 Surface Fire Behavior Worksheet

This comprehensive worksheet can be used with the surface fire behavior lookup tables, the Nomograms and Nomographs, as well as BehavePlus runs if you want a paper copy.

Consider using this as your briefing documentation by including a weather forecast narrative, your thoughts about recent fire activity, your sense of how accurate the predictions seem, and when you expect changes through the burn period.

Incident/Project: **Observer/Analyst:** **Date:**

	Time and Place				**Notes**
1	Projection Point Identifier				
2	Projection Month/Day				
3	Projection Hour of the Day				
4	Burn Period/Duration, hr or min				
	Section 2. Fuel/Terrain				
5	**Surface Fuel Model**				
6	Canopy Cover, %				
7	Aspect (N, E ,S ,W)				
8	**Slope, %**				
	Section 3. Dead Fuel Moisture – add 1-2 % each for 10-hr and 100-hr				
9	Cloud Cover, %				
10	Dry Bulb Temperature, °F				
11	Wet Bulb Temperature, °F				
12	Relative Humidity, %				
13	Reference Fuel Moisture, %				
14	(S)haded or (U)nshaded				
15	Elevation Difference (B, L, A)				
16	Fuel Moisture Correction, %				
17	**1-hr Moisture Content (L13 + L15)**				
18	**Probability of Ignition**				
	Section 3. Live Fuel Moisture				
19	**Herbaceous Moisture Content, %**				
20	**Woody Moisture Content, %**				
	Section 1. Windspeed and Wind Direction				
21	Wind Direction				
22	Surface (20ft) Windspeed, mph				
23	(S)heltered or (U)nsheltered				
24	Wind Adjustment Factor				
25	Midflame Windspeed, mph				
26	**Effective Windspeed, mph**				
	Section 5. Fire Behavior				
27	**Probability of Ignition**				
28	Spread Direction				(H)ead, (B)ack, (F)lank
29	Direction of Max Spread				
30	Head Fire Rate of Spread (HFROS)				Chains (66ft)/hour
31	Head Fire Flame Length (HFFL)				Feet
32	Fraction of HFROS				
33	Fraction of HFFL				
34	**ROS in Spread Direction**				Chains (66ft)/hour
35	**FL in Spread Direction**				Feet
	Section 6. Fire Size and Shape				**Notes**
36	Spread Distance, chains (66ft)				
37	**Fire Size, acres**				
38	**Fire Perimeter, chains (66ft)**				

5.1.1 Available Tools and Resources

This section describes how to estimate expected surface fire behavior and provides several references tools used in the process:

1. ***A Worksheet (found at 5.1)*** designed to document a complete assessment for surface fire behavior and growth using either the lookup tables or the nomographs.
2. ***EWS Tables (found at 5.3)*** for estimating Effective Windspeed from Slope and Midflame Windspeed. The Effective Windspeeds that result from these tables assumes that wind is blowing ± 30° from upslope. For other situations, manual vectoring using the EWS Table would be necessary.
3. ***Surface Fire Behavior Lookup Tables (found at 5.4)*** for making estimates of surface fire spread and flame length. Note these assumptions
   - 10-hr and 100-hr moisture values of 6% and 8% are used in the lookup tables.
   - The *20ft/FCST wind line is provided as a convenience, but only works with stated WAF & no slope adjustments.
   - Backing & flanking columns are only rough estimates based on ½ & 1 mph windspeeds. Use the Flanking and Backing Nomograph (found at 5.5) or BehavePlus for more precise estimates.
4. Instructions for ***Surface Fire Behavior Nomographs and Nomograms (found at 5.4)***
5. ***Flanking and Backing Fire Behavior Nomograph (found at 5.5)*** for estimating rate of spread and flame length where fire is spreading more slowly on the flanks and at the back of the fire perimeter.

These tools can help you make expected surface fire behavior estimates. Consider the following:

5.1.2 Required Surface Model Inputs

- **Windspeed and Direction** from Sections 1 (20 ft & Midflame) and 5 (Effective Windspeed)
- **Fuel Model** from Section 2 (Surface Fuel Model, Canopy Characteristics)
- **Dead Fuel Moisture** from Section 3 (Temp, RH, Month, Time, Elev Diff, Shading, Slope)
- **Live Fuel Moisture** from Section 3 (Herbaceous Moisture Content, Woody Moisture Content)
- **Slope and Aspect** from Section 4 (Mapping)
- **Time and Place** from Section 7 (Burn Period, Duration)

5.1.3 Surface Model Outputs

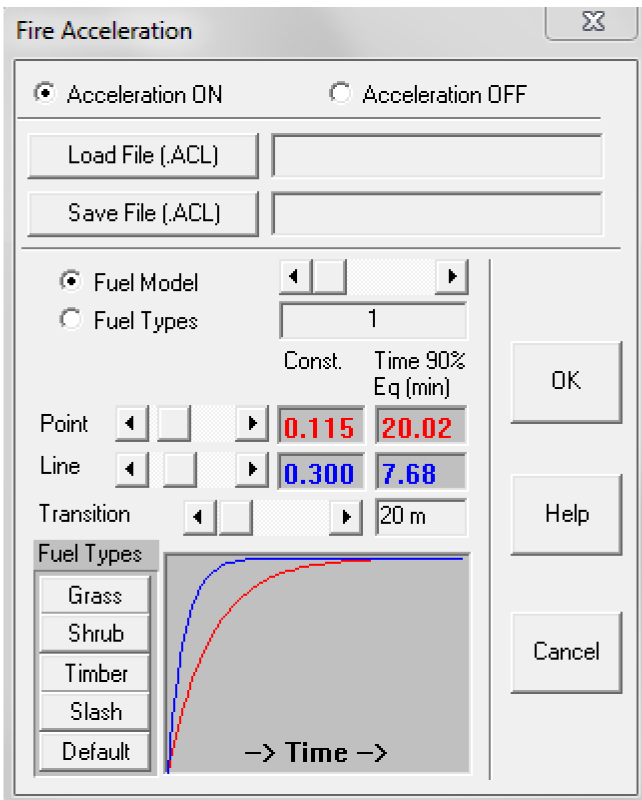
- **Rate of Spread** is useful in fireline tactical applications; identifying what is at risk in the burn period, escape route limitations,
- **Flame Length/Fireline Intensity** is used generally in determining what tactics make sense during the peak burn period, interpreting safety zone concerns, and suggesting spotting potential
- **Heat per Unit Area** is available from nomograms and BehavePlus. Like Energy Release Component, it may be helpful in suggesting burn duration and fire effects.

5.1.4 Acceleration Effect on Rate of Spread

Fire acceleration is defined as the rate of increase in fire spread rate. It affects the amount of time required for a fire spread rate to achieve the theoretical steady state spread rate given 1) its existing spread rate, and 2) constant environmental conditions.

Because initiating fires can take 20 minutes to over an hour to reach a steady spread rate, fire behavior and fire growth can be significantly reduced in the first burn period and when beginning to spread in subsequent periods.

Conversely, calibration efforts, based on this early growth period, that do not consider acceleration can lead to significant under prediction in subsequent burn periods.



At this time, fire acceleration is implemented only in FARSITE, using the model developed for the Canadian Forest Fire Behavior Prediction System (Alexander et. al. 1992).

It is active by default, but can be turned off as a model input.

As implemented, inputs are segregated by type of Ignition (**point** vs. **line** source) and potentially by **fuel type** (grass, shrub, timber, slash, a default, or by fuel model).

Grass fuels are expected to have more rapid acceleration rates (shorter time to reach equilibrium) than fuel types with larger woody material (slash etc.).

5.2 Effective Windspeed (EWS)

EWS integrates the effect of winds and slope on a surface fire behavior estimate. These tables produce the resulting EWS ***when winds are blowing upslope***.

For downslope and cross-slope winds, use the "0" mph row in the Midflame Windspeed (MFWS) column to estimate the "slope equivalent windspeed." It can be used as the MFWS in the lookup tables to produce slope vector fire behavior estimates for use in the vectoring process (5.2)

Fuel Models 1, 2, 9; Effective Windspeed (EWS), in mph

MFWS (mph)	Slope Steepness									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
0	1	1	2	3	3	4	5	5	6	7
2	2	2	3	3	4	4	5	6	6	7
4	4	4	5	5	5	6	6	7	7	8
6	6	6	6	7	7	7	8	8	9	9
8	8	8	8	8	9	9	9	9	10	11
10	10	10	10	10	11	11	11	12	12	13
12	12	12	12	12	13	13	13	14	14	14
14	14	14	14	14	15	15	15	15	16	16
16	16	16	16	16	16	17	17	17	18	18
18	18	18	18	18	18	19	19	19	19	20
20	20	20	20	20	20	21	21	21	21	22

Fuel models 3, 4, 5, 6, 7, 8, 10; Effective Windspeed (EWS), in mph

MFWS (mph)	Slope Steepness									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
0	0	1	1	2	3	3	4	5	6	7
2	2	2	3	3	4	5	5	6	7	8
4	4	4	5	5	5	6	7	8	8	9
6	6	6	7	7	7	8	9	9	10	11
8	8	8	8	9	9	10	10	11	12	12
10	10	10	10	11	11	11	12	13	13	14
12	12	12	12	13	13	13	14	15	15	16
14	14	14	14	15	15	15	16	16	17	18
16	16	16	16	17	17	17	18	18	19	20
18	18	18	18	19	19	19	20	20	21	21
20	20	20	20	21	21	21	21	22	23	23

Fuel models 11, 12, 13; Effective Windspeed (EWS), in mph

MFWS (mph)	Slope Steepness									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
0	0	1	1	2	3	4	5	6	7	9
2	2	2	3	3	4	5	6	7	9	10
4	4	4	5	5	6	7	8	9	10	12
6	6	6	7	7	8	9	10	11	12	14
8	8	8	9	9	10	11	12	13	14	15
10	10	10	11	11	12	13	14	15	16	17
12	12	12	13	13	14	15	16	17	18	19
14	14	14	15	15	16	17	18	19	20	21
16	16	16	17	17	18	19	19	21	22	23
18	18	18	19	19	20	20	21	22	24	25
20	20	20	21	21	22	22	23	24	25	26

5.3 Surface Fire Behavior Lookup Tables

5.3.1 Fuel Model 1 (Short Grass – 1 ft)

Fire spread is governed by the fine, very porous, and continuous herbaceous fuels that have cured or are nearly cured. Fires are surface fires that move rapidly through the cured grass and associated material. Very little shrub or timber is present, generally less than 1/3 of the area. Grasslands and savanna are represented along with stubble, grass-tundra, and grass-shrub combinations that met the above area constraint. Annual and perennial grasses are included in this fuel model.

SPREAD Ch/hr		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	8	9	14	32	111	247	442	697	1014	1145	1145	1145	1145
	2	6	7	11	26	90	201	360	568	666	666	666	666	666
	3	5	6	9	22	77	172	307	446	446	446	446	446	446
	4	5	6	8	20	69	154	275	345	345	345	345	345	345
	5	4	5	8	19	64	143	255	297	297	297	297	297	297
	6	4	5	7	18	61	135	242	270	270	270	270	270	270
	7	4	5	7	17	57	127	228	242	242	242	242	242	242
	8	4	4	6	15	52	117	199	199	199	199	199	199	199
	9	3	4	6	13	45	101	136	136	136	136	136	136	136
	10	2	3	4	10	35	65	65	65	65	65	65	65	65
	11	1	2	2	6	13	13	13	13	13	13	13	13	13
	12	0	0	0	0	0	0	0	0	0	0	0	0	0

FLAME Feet		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	2	2	2	3	6	9	11	14	17	18	18	18	18
	2	1	2	2	3	5	7	10	12	13	13	13	13	13
	3	1	1	2	3	4	6	8	10	10	10	10	10	10
	4	1	1	2	2	4	6	8	9	9	9	9	9	9
	5	1	1	2	2	4	6	7	8	8	8	8	8	8
	6	1	1	1	2	4	5	7	7	7	7	7	7	7
	7	1	1	1	2	4	5	7	7	7	7	7	7	7
	8	1	1	1	2	3	5	6	6	6	6	6	6	6
	9	1	1	1	2	3	4	5	5	5	5	5	5	5
	10	1	1	1	1	2	3	3	3	3	3	3	3	3
	11	0	1	1	1	1	1	1	1	1	1	1	1	1
	12	0	0	0	0	0	0	0	0	0	0	0	0	0

5.3.2 Fuel Model 2 (Timber – Grass and Understory)

Fire spread is primarily through the fine herbaceous fuels, either curing or dead. These are surface fires where the herbaceous material, as well as litter and dead/down stemwood from the open shrub or timber overstory, contribute to the fire intensity. Open shrub lands and pine stands or scrub oak stands that cover one-third to two-thirds of the area may generally fit this model. Such stands may include clumps of fuels that generate higher intensities and that may produce firebrands. Some pinyon-juniper included here.

SPREAD Ch/hr	Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*FCST/20ft	NWNS-0	Back - ½	Flank - 1	7	13	20	27	33	40	47	53	60	67
EWS				2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %; (Herbaceous moisture 120% - 80%) 1	3-4	4-5	6-7	12-14	36-41	71-82	118-136	176-202	245-281	324-371	412-473	511-586	619-710
3	3	3-4	5	10-11	28-32	56-64	93-106	138-158	192-220	253-290	323-370	400-458	484-555
5	2-3	3	4-5	8-10	24-27	48-55	79-91	118-135	164-188	217-248	277-316	343-392	415-475
7	2	3	4	8-9	22-25	44-50	73-83	108-123	150-171	198-226	253-288	313-357	379-432
9	2	2-3	3-4	7-8	20-23	40-46	66-76	99-113	138-157	182-207	232-264	287-327	348-396
11	2	2	3	6-7	17-20	34-39	57-65	85-97	118-134	155-177	198-226	245-280	297-339
13	1	1-2	2	4-5	12-14	24-27	40-45	60-68	83-94	110-124	140-159	173-196	210-238
15	0	0-1	0-1	0-2	0-4	0-9	0-13	0-13	0-13	0-13	0-13	0-13	0-13
17	0	0	0	0	0	0	0	0	0	0	0	0	0

FLAME Ch/hr	Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST	NWNS-0	Back - ½	Flank - 1	7	13	20	27	33	40	47	53	60	67
EWS				2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %; (Herbaceous moist. 120% - 80%) 1	2-3	3	3-3	5	7-8	10-11	13-14	15-16	18-19	20-22	23-24	25-27	27-29
3	2	2	3-3	4	6	8-9	10-11	12-13	14-16	16-18	18-20	20-22	22-24
5	2	2	2-3	3-4	5-6	7-8	9-10	11-12	13-14	15-16	16-18	18-19	20-21
7	2	2	2	3	5	7	9	10-11	12-13	14-15	15-16	17-18	18-20
9	2	2	2	3	5	6-7	8-9	10	11-12	13-14	14-16	16-17	17-19
11	1	2	2	3	4	6	7-8	9	10-11	11-12	13-14	14-15	15-17
13	1	1	1	2	3	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12
15	0	<1	<1	0-1	0-1	0-2	0-2	0-2	0-2	0-2	0-2	0-2	0-2
17	0	0	0	0	0	0	0	0	0	0	0	0	0

5.3.3 Fuel Model 3 (Tall Grass – 2.5 ft)

Fires in this fuel are the most intense of the grass group and display high rates of spread under the influence of wind. Wind may drive fire into the upper heights of the grass and across standing water. Stands are tall, averaging about 3 feet (1 m), but considerable variation may occur. Approximately 1/3 or more of the stand is considered dead or cured and maintains the fire. Wild or cultivated grains that have not been harvested can be considered similar to tall prairie and marshland grasses.

SPREAD Ch/hr		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS/0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	8	18	32	68	157	261	377	502	636	776	923	1076	1234
	3	6	14	25	52	121	201	290	387	490	598	712	829	951
	5	5	11	20	42	97	162	234	312	395	482	574	669	767
	7	4	9	17	36	82	137	198	264	335	409	486	566	650
	9	4	8	15	32	73	122	176	234	296	362	430	501	575
	11	3	8	14	29	67	111	161	214	271	331	393	458	526
	13	3	7	13	27	62	103	149	198	251	306	364	425	487
	15	3	6	12	25	57	95	137	182	231	282	335	391	448
	17	3	6	10	22	51	85	122	163	207	252	300	350	401
	19	2	5	9	19	43	71	103	137	174	212	253	294	338
	21	2	4	7	14	32	53	77	103	130	159	189	194	194
	23	1	2	4	8	18	30	43	54	54	54	54	54	54

FLAME feet		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS/0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	5	7	9	12	18	23	27	31	35	38	41	44	47
	3	4	5	7	10	15	19	22	25	28	31	34	36	38
	5	3	5	6	9	13	16	19	22	24	26	28	31	33
	7	3	4	5	8	11	14	17	19	21	23	25	27	29
	9	3	4	5	7	10	13	15	18	20	21	23	25	27
	11	2	4	5	7	10	12	15	17	19	20	22	24	25
	13	2	3	5	6	9	12	14	16	18	19	21	23	24
	15	2	3	4	6	9	11	13	15	17	19	20	22	23
	17	2	3	4	6	8	10	12	14	16	17	19	20	21
	19	2	3	4	5	7	9	11	12	14	15	16	17	19

5.3.4 Fuel Model 4 (Chaparral – 6 ft)

Intense and fast-spreading fires involve the foliage and live and dead fine woody material in the crowns of a nearly continuous secondary overstory. Stands of mature shrubs, 6 or more feet tall, such as California mixed chaparral, the high pocosin along the east coast, the pine barrens of New Jersey, or the closed jack pine stands of the north-central States are typical candidates. Besides flammable foliage, dead woody material in the stands significantly contributes to the fire intensity. Height of stands qualifying for this model depends on local conditions. A deep litter layer may also hamper suppression efforts.

SPREAD Ch/hr		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.5)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	4	8	12	16	20	24	28	32	36	40
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %; (Woody moisture 120% - 80%)	1	5-6	8-11	13-18	27-37	65-88	111-151	165-224	225-306	290-394	359-489	433-589	511-695	593-807
	3	4-6	7-9	11-16	24-32	56-76	97-132	144-195	196-266	253-343	313-425	378-513	446-605	517-702
	5	4-5	6-8	10-14	21-29	51-69	88-118	130-176	178-239	229-309	284-383	343-462	404-545	469-632
	7	4-5	6-8	10-13	20-27	48-64	83-110	122-163	167-222	215-286	267-355	322-429	380-506	440-587
	9	3-4	6-7	9-12	19-25	46-61	79-104	118-155	160-211	206-271	256-337	309-406	365-479	423-556
	11	3-4	5-7	9-12	19-24	44-58	76-100	113-148	154-201	199-259	247-322	298-388	351-458	408-531
	13	3-4	5-7	8-11	17-23	41-55	71-95	105-140	143-191	184-246	229-306	276-369	325-435	377-504
	15	2-4	4-6	6-10	13-21	30-50	52-87	77-129	105-175	135-226	167-281	202-338	238-399	276-463
	17	1-3	2-5	3-8	6-16	14-38	25-65	37-96	50-130	65-168	80-209	97-252	114-297	133-344
	19	1	1	2	3-4	8-10	14-17	20-25	27-34	35-44	44-55	53-66	62-78	72-90

FLAME feet		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.5)												
20ft/FCST		NWNS-0	Back - ½	Flank - 1	4	8	12	16	20	24	28	32	36	40
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %; (Woody moisture 120% - 80%)	1	6-7	8-9	10-11	13-16	20-24	26-30	31-36	36-42	40-47	44-52	48-57	52-61	56-66
	3	5-6	7-8	9-10	12-14	18-21	23-27	27-32	32-37	36-42	39-46	43-50	46-54	49-58
	5	5-6	6-7	8-9	11-13	16-19	21-25	25-30	29-34	33-38	36-42	39-46	43-50	46-53
	7	5	6-7	8-9	10-12	16-18	20-23	24-28	28-32	31-36	34-40	37-43	40-47	43-50
	9	5	6-7	7-8	10-12	15-17	19-22	23-27	27-31	30-35	33-38	36-42	39-45	42-48
	11	4-5	6-6	7-8	10-11	15-17	19-22	23-26	26-30	29-34	32-37	35-40	38-44	41-47
	13	4-5	5-6	7-8	9-11	14-16	18-21	21-25	24-29	28-32	30-36	33-39	36-42	38-45
	15	3-5	4-6	5-7	7-10	10-15	13-19	16-23	18-27	21-30	23-33	25-36	27-39	29-42
	17	2-3	2-3	3-6	4-8	5-12	7-15	8-18	9-21	11-23	12-25	13-28	14-30	15-32
	19	1	1	2	2	3	4	5	5-6	6-7	7	7-8	8-9	9

5.3.5 Fuel Model 5 (Brush – 2 ft)

Fire is generally carried in the surface fuels that are made up of litter cast by the shrubs and the grasses or forbs in the understory. The fires are generally not very intense because surface fuel loads are light, the shrubs are young with little dead material, and the foliage contains little volatile material. Usually shrubs are short and almost totally cover the area. Young, green stands with no dead wood would qualify: laurel, vine maple, alder, or even chaparral, manzanita, or chamise.

SPREAD Ch/hr		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %; (Woody moisture 120% - 80%)	1	1–2	2-3	4-6	8-12	20-28	34-48	50-70	67-95	86-122	107-151	128-181	151-214	175-247
	3	1-2	2-3	3-5	7-11	17-25	28-43	42-63	57-86	73-110	90-136	109-164	128-193	148-223
	5	1	2-3	3-5	5-10	13-23	22-40	32-59	44-79	56-102	70-126	84-152	98-178	114-206
	7	<1	1-2	1-4	3-9	6-22	10-37	15-54	20-74	22-95	22-117	22-141	22-165	22-191
	9	<1	1-2	1-4	2-8	6-18	10-32	14-47	19-63	20-81	20-100	20-120	20-142	20-164
	11	<1	1	1-2	2-4	5-9	9-16	14-23	19-32	19-41	19-46	19-46	19-46	19-46
	13	<1	1	1	2-3	5-7	9-12	13-17	17-22	17-22	17-22	17-22	17-22	17-22
	15	<1	<1	1	2-3	5-6	8-10	11-15	12-16	12-16	12-16	12-16	12-16	12-16
	17	<1	<1	<1	1-2	3-5	6-8	7-9	7-9	7-9	7-9	7-9	7-9	7-9
	19	<1	<1	<1	1	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2

FLAME feet		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %; (Woody moisture 120% - 80%)	1	2	2-3	3	4-5	6-7	8-9	9-11	11-13	12-14	13-16	14-17	15-19	17-20
	3	1-2	2	3	4	5-7	7-9	8-10	9-12	10-13	11-14	12-16	13-17	14-18
	5	1-2	2	2-3	3-4	4-6	5-8	6-10	7-11	8-12	9-14	10-15	10-16	11-17
	7	1-2	1-2	1-3	1-4	2-6	3-7	3-9	4-10	4-12	4-13	4-14	4-15	4-16
	9	1	1-2	1-2	1-3	2-5	3-7	3-8	3-9	3-10	3-11	3-12	3-13	3-14
	11	1	1	1	1-2	2-3	2-4	3-4	3-5	3-5	3-6	3-6	3-6	3-6
	13	1	1	1	1	2	2-3	3	3-4	3-4	3-4	3-4	3-4	3-4
	15	0-1	1	1	1	2	2	2-3	3	3	3	3	3	3
	17	<1	0-1	0-1	1	1	2	2	2	2	2	2	2	2
	19	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

5.3.6 Fuel Model 6 (Dormant Brush, Hardwood Slash)

Fires carry through the shrub layer where the foliage is more flammable than fuel model 5, but this requires moderate winds, greater than 8 mi/h (13 km/h) at midflame height. Fire will drop to the ground at low wind speeds or at openings in the stand. The shrubs are older. A broad range of shrub conditions is covered by this model. Fuel situations to be considered include intermediate stands of chamise, chaparral, oak brush, low pocosin, Alaskan spruce taiga, and shrub tundra. Even hardwood slash that has cured can be considered. Pinyon-juniper shrublands may be represented but may over-predict rate of spread except at high winds.

SPREAD Ch/hr		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS/0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	3	5	9	19	42	71	103	138	175	215	257	300	345
	3	2	4	7	15	34	56	82	110	139	171	204	239	274
	5	2	4	6	12	28	47	68	91	115	141	168	197	226
	7	2	3	5	10	24	40	58	78	99	121	145	169	181
	9	1	3	5	9	21	36	52	69	88	108	129	150	150
	11	1	2	4	8	19	33	47	63	81	99	118	132	132
	13	1	2	4	8	18	30	44	59	75	92	109	120	120
	15	1	2	4	7	17	28	41	55	70	85	102	109	109
	17	1	2	3	7	15	26	38	50	64	78	93	96	96
	19	1	2	3	6	14	23	33	45	57	70	78	78	78
	21	1	1	3	5	12	19	28	38	48	55	55	55	55
	23	1	1	2	4	9	15	21	29	31	31	31	31	31
	25	<1	1	1	2	5	9	10	10	10	10	10	10	10

FLAME feet		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS/0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	5	8	10	12	14	15	17	18	19	21	5	8	10
	3	5	7	8	10	11	13	14	15	16	17	5	7	8
	5	4	6	7	9	10	11	12	13	14	15	4	6	7
	7	4	5	7	8	9	10	11	12	13	13	4	5	7
	9	3	5	6	7	8	9	10	11	12	12	3	5	6
	11	3	5	6	7	8	9	10	10	11	11	3	5	6
	13	3	4	6	7	7	8	9	10	10	10	3	4	6
	15	3	4	5	6	7	8	9	10	10	10	3	4	5
	17	3	4	5	6	7	8	8	9	9	9	3	4	5
	19	3	4	5	5	6	7	8	8	8	8	3	4	5
	21	2	3	4	5	5	6	6	6	6	6	2	3	4
	23	2	3	3	4	4	4	4	4	4	4	2	3	3
	25	1	2	2	2	2	2	2	2	2	2	1	2	2

5.3.7 Fuel Model 7 (Southern Rough)

Fires burn through the surface and shrub strata with equal ease and can occur at higher dead fuel moisture contents because of the flammability of live foliage and other live material. Stands of shrubs are generally between 2 and 6 feet (0.6 and 1.8 m) high. Palmetto-Gallberry understory-pine overstory sites are typical and low pocosins may be represented. Black spruce-shrub combinations in Alaska may also be represented.

SPREAD Ch/hr		**Effective Windspeed(EWS), mph** *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %; (Woody moisture 120% - 80%)	3	1-2	3	5-6	10-12	23-28	38-47	56-68	74-91	94-115	116-141	138-168	161-197	185-226
	6	1	2-3	4-5	9-10	20-24	33-40	48-58	64-78	81-99	100-121	119-144	139-169	160-194
	9	1	2-3	4-5	8-9	17-21	29-35	42-51	57-68	72-87	88-106	105-127	123-148	141-170
	12	1	2	3-4	7-8	16-19	26-32	38-46	51-62	65-78	80-96	95-114	112-134	119-147
	15	1	2	3-4	6-8	15-17	25-29	36-42	48-57	60-72	74-88	88-105	103-123	105-129
	18	1	2	3	6-7	14-16	23-27	33-40	45-53	57-68	70-83	83-99	96-115	96-117
	21	1	2	3	6-7	13-15	22-26	32-37	42-50	54-64	66-78	79-93	89-108	89-108
	24	1	2	3	5-6	12-15	21-24	30-35	40-47	51-60	63-74	75-88	82-100	82-100
	27	1	1-2	2-3	5-6	12-14	19-23	28-33	38-44	48-56	59-69	70-83	74-91	74-91

FLAME feet		**Effective Windspeed(EWS), mph** *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %; (Woody moisture 120% - 80%)	3	2-2	2	3	4-4	6-6	7-8	8-9	10-11	11-12	12-13	13-14	14-15	15-16
	6	1-2	2	2-3	3-4	5-6	6-7	8-8	9-10	10-11	11-12	11-13	12-14	13-14
	9	1-1	2	2-3	3-3	5-5	6-6	7-8	8-9	9-10	10-11	10-12	11-12	12-13
	12	1-1	2	2	3-3	4-5	5-6	6-7	7-8	8-9	9-10	10-11	10-11	11-12
	15	1-1	2	2	3-3	4-4	5-6	6-7	7-8	8-9	9-9	9-10	10-11	10-11
	18	1-1	2	2	3-3	4-4	5-5	6-6	7-7	7-8	8-9	9-10	9-10	9-11
	21	1-1	1-2	2	3-3	4-4	5-5	6-6	6-7	7-8	8-9	9-9	9-10	9-10
	24	1-1	1-2	2	2-3	4-4	5-5	5-6	6-7	7-8	8-8	8-9	9-10	9-10
	27	1-1	1	2	2-3	3-4	4-5	5-6	6-7	7-7	7-8	8-9	8-9	8-9

5.3.8 Fuel Model 8 (Closed Timber Litter)

Slow-burning ground fires with low flame lengths are generally the case, although the fire may encounter an occasional "jackpot" or heavy fuel concentration that can flare up. Only under severe weather conditions involving high temperatures, low humidities, and high winds do the fuels pose fire hazards. Closed canopy stands of short-needle conifers or hardwoods that have leafed out support fire in the compact litter layer. This layer is mainly needles, leaves, and occasionally twigs because little undergrowth is present in the stand. Representative conifer types are white pine, and lodgepole pine, spruce, fir, and larch.

SPREAD Ch/hr		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes sheltered wind adjustment (0.2)												
*20ft/FCST		NWNS/0	Back - ½	Flank - 1	10	20	30	40	50	60	70	80	90	100
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	0	1	1	1	3	4	6	9	11	13	13	13	13
	3	0	<1	1	1	2	3	5	7	8	8	8	8	8
	5	0	<1	<1	1	2	3	4	6	6	6	6	6	6
	7	0	<1	<1	1	1	2	4	4	4	4	4	4	4
	9	0	0	<1	1	1	2	3	3	3	3	3	3	3
	11	0	0	<1	1	1	2	3	3	3	3	3	3	3
	13	0	0	<1	0	1	2	3	3	3	3	3	3	3
	15	0	0	<1	0	1	2	2	2	2	2	2	2	2
	17	0	0	0	0	1	2	2	2	2	2	2	2	2
	19	0	0	0	0	1	1	2	2	2	2	2	2	2
	21	0	0	0	0	1	1	2	2	2	2	2	2	2
	23	0	0	0	0	1	1	1	1	1	1	1	1	1

FLAME feet		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes sheltered wind adjustment (0.2)												
*20ft/FCST		NWNS/0	Back - ½	Flank - 1	10	20	30	40	50	60	70	80	90	100
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	1	1	1	1	1	2	2	2	3	3	3	3	3
	3	1	1	1	1	1	2	2	2	2	2	2	2	2
	5	0	1	1	1	1	1	2	2	2	2	2	2	2
	7	0	<1	1	1	1	1	1	2	2	2	2	2	2
	9	0	<1	1	1	1	1	1	1	1	1	1	1	1
	11	0	<1	<1	1	1	1	1	1	1	1	1	1	1
	13	0	<1	<1	1	1	1	1	1	1	1	1	1	1
	15	0	<1	<1	1	1	1	1	1	1	1	1	1	1
	17	0	<1	<1	0	1	1	1	1	1	1	1	1	1
	19	0	<1	<1	0	1	1	1	1	1	1	1	1	1
	21	0	<1	<1	0	1	1	1	1	1	1	1	1	1
	23	0	<1	<1	0	1	1	1	1	1	1	1	1	1

5.3.9 Fuel Model 9 (Hardwood Litter)

Fires run through the surface litter faster than model 8 and have longer flame height. Both long-needle conifer stands and hardwood stands, especially the oak-hickory types, are typical. Fall fires in hardwoods are predictable, but high winds will cause higher rates of spread than predicted because of spotting caused by rolling and blowing leaves. Closed stands of long-needled pine like ponderosa, Jeffrey, and red pines, or southern pine plantations are grouped in this model. Concentrations of dead-down woody material will contribute to possible torching of trees, spotting, and crowning.

SPREAD Ch/hr		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes prtly shelterd wind adjustment (0.3)												
*FCST/20ft		NWNS-0	Back - ½	Flank - 1	7	13	20	27	33	40	47	53	60	67
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	1	2	2	4	11	20	33	47	64	83	104	127	152
	3	1	1	2	3	8	16	25	36	49	64	80	98	118
	5	1	1	2	3	7	13	20	29	40	52	65	79	95
	7	1	1	1	2	6	11	17	25	34	44	55	67	80
	9	1	1	1	2	5	10	15	22	30	39	49	60	71
	11	1	1	1	2	5	9	14	20	27	36	45	54	65
	13	1	1	1	2	4	8	13	19	25	33	41	50	60
	15	1	1	1	2	4	7	12	17	23	30	38	46	56
	17	0	1	1	1	4	7	11	15	21	27	34	42	48
	19	0	1	1	1	3	6	9	13	18	23	29	33	33
	21	0	<1	1	1	2	4	7	10	13	17	17	17	17
	23	0	<1	<1	1	1	2	4	4	4	4	4	4	4

FLAME feet		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes prtly shelterd wind adjustment (0.3)												
*FCST/20ft		NWNS-0	Back - ½	Flank - 1	7	13	20	27	33	40	47	53	60	67
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	2	2	2	3	4	5	6	8	9	10	11	12	13
	3	1	1	2	2	3	4	5	6	7	8	9	10	11
	5	1	1	1	2	3	4	4	5	6	7	8	8	9
	7	1	1	1	2	2	3	4	5	5	6	7	7	8
	9	1	1	1	1	2	3	4	4	5	6	6	7	7
	11	1	1	1	1	2	3	3	4	5	5	6	6	7
	13	1	1	1	1	2	3	3	4	4	5	6	6	7
	15	1	1	1	1	2	3	3	4	4	5	5	6	6
	17	1	1	1	1	2	2	3	3	4	4	5	5	6
	19	1	1	1	1	2	2	3	3	3	4	4	5	5
	21	0	1	1	1	1	2	2	2	3	3	3	3	3
	23	0	<1	<1	0	1	1	1	1	1	1	1	1	1

5.3.10 Fuel Model 10 (Timber – Litter and Understory)

The fires burn in the surface and ground fuels with greater fire intensity than the other timber litter models. Dead-down fuels include greater quantities of 3-inch (7.6-cm) or larger limbwood resulting from overmaturity or natural events that create a large load of dead material on the forest floor. Crowning out, spotting, and torching of individual trees are more frequent in this fuel situation, leading to potential fire control difficulties. Any forest type may be considered if heavy down material is present; examples are insect- or disease-ridden stands, windthrown stands, overmature situations with deadfall, and aged light thinning or partial-cut slash.

SPREAD Ch/hr		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes prtly shelterd wind adjustment (0.3)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	7	13	20	27	33	40	47	53	60	67
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %; (Woody moisture 120% - 80%)	1	1	1-2	2	3-4	8-10	13-17	19-25	25-33	33-43	41-53	49-64	58-76	67-88
	3	1	2	2	3-4	7-9	11-15	16-22	22-29	29-38	35-47	43-56	50-66	59-77
	5	1	1	1-2	3-3	6-8	10-13	15-19	20-26	26-34	32-42	38-50	45-59	52-69
	7	1	1	1-2	2-3	5-7	9-12	13-18	18-24	24-31	29-38	35-46	42-54	48-63
	9	1	1	1-2	2-3	5-7	9-11	13-16	17-22	22-29	27-36	33-43	39-51	45-59
	11	1	1	1-2	2-3	5-6	8-11	12-16	16-21	21-27	26-34	32-41	37-48	43-56
	13	1	1	1-2	2-3	5-6	8-10	12-15	16-20	20-26	25-32	30-39	36-46	41-53
	15	1	1	1	2-3	4-6	8-10	11-14	15-19	19-25	24-31	29-37	34-43	40-50
	17	1	1	1	2	4-5	7-9	11-13	14-18	18-23	23-29	28-34	33-41	38-47
	19	<1	1	1	2	4-5	7-8	10-12	13-16	17-21	21-26	25-32	30-37	35-43
	21	<1	1	1	1-2	3-4	5-7	8-11	11-14	14-19	17-23	21-28	25-33	29-38

FLAME feet		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes prtly shelterd wind adjustment (0.3)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	7	13	20	27	33	40	47	53	60	67
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %; (Woody moisture 120% - 80%)	1	2	2-3	3	4	5-6	7-8	8-9	9-11	11-12	12-13	13-15	14-16	15-17
	3	2	2	3	3-4	5-6	6-7	7-8	8-10	9-11	10-12	11-13	12-14	13-15
	5	2	2	2-3	3-4	4-5	6	7-8	8-9	9-10	9-11	10-12	11-13	12-14
	7	2	2	2-3	3	4-5	5-6	6-7	7-8	8-9	9-10	10-11	10-12	11-13
	9	1-2	2	2	3	4	5-6	6-7	7-8	8-9	8-10	9-11	10-11	11-12
	11	1-2	2	2	3	4	5-6	6-7	7-8	7-8	8-9	9-10	10-11	10-12
	13	1-2	2	2	3	4	5	6	6-7	7-8	8-9	9-10	9-11	10-11
	15	1-2	2	2	2-3	4	5	5-6	6-7	7-8	8-9	8-10	9-10	10-11
	17	1	2	2	2-3	3-4	4-5	5-6	6-7	7-8	7-8	8-9	9-10	9-10
	19	1	1-2	2	2	3-4	4-5	5	6	6-7	7-8	8	8-9	9-10
	21	1	1	1-2	2	3	3-4	4-5	5-6	5-6	6-7	6-8	7-8	7-9

5.3.11 Fuel Model 11 (Light Logging Slash)

Fires are fairly active in the slash and herbaceous material intermixed with the slash. The spacing of the rather light fuel load, shading from overstory, or the aging of the fine fuels can contribute to limiting the fire potential. Light partial cuts or thinning operations in mixed conifer stands, hardwood stands, and southern pine harvests are considered. Clearcut operations generally produce more slash than represented here. The less-than-3-inch (7.6-cm) material load is less than 12 tons per acre (5.4 t/ha). The greater-than-3-inch (7.6-cm) is represented by not more than 10 pieces, 4 inches (10.2 cm) in diameter, along a 50-foot (15-m) transect.

SPREAD Ch/hr		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS/0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	1	2	2	4	8	12	16	20	25	29	34	39	43
	3	1	1	2	3	6	9	13	16	20	23	27	31	35
	5	1	1	2	3	5	8	11	14	17	20	23	26	30
	7	1	1	1	2	5	7	10	12	15	18	21	24	27
	9	<1	1	1	2	4	7	9	11	14	17	19	22	25
	11	<1	1	1	2	4	6	8	10	12	15	17	19	22
	13	<1	1	1	2	3	5	6	8	10	12	14	16	16
	15	<1	<1	1	1	2	3	4	5	6	7	7	7	7

FLAME feet		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS/0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	2	2	3	3	4	5	6	7	7	8	9	9	10
	3	1	2	2	3	4	4	5	6	6	7	7	8	8
	5	1	2	2	2	3	4	5	5	6	6	6	7	7
	7	1	1	2	2	3	4	4	5	5	6	6	6	7
	9	1	1	2	2	3	4	4	5	5	5	6	6	6
	11	1	1	2	2	3	3	4	4	5	5	5	6	6
	13	1	1	1	2	2	3	3	4	4	4	4	5	5
	15	1	1	1	1	2	2	2	2	3	3	3	3	3

5.3.12 Fuel Model 12 (Medium Logging Slash)

Rapidly spreading fires with high intensities capable of generating firebrands can occur. When fire starts, it is generally sustained until a fuel break or change in fuels is encountered. The visual impression is dominated by slash and much of it is less than 3 inches (7.6 cm) in diameter. The fuels total less than 35 tons per acre (15.6 t/ha) and seem well distributed. Heavily thinned conifer stands, clearcuts, and medium or heavy partial cuts are represented. The material larger than 3 inches (7.6 cm) is represented by encountering 11 pieces, 6 inches (15.2 cm) in diameter, along a 50-foot (15-m) transect.

SPREAD Ch/hr		**Effective Windspeed(EWS), mph** *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	2	4	5	9	17	25	34	43	52	62	72	82	92
	3	2	3	4	7	14	20	28	35	43	50	58	66	75
	5	2	2	4	6	11	17	23	30	36	43	50	56	63
	7	1	2	3	5	10	15	21	26	32	38	44	50	56
	9	1	2	3	5	9	14	19	24	29	34	40	45	51
	11	1	2	3	5	9	13	17	22	27	32	37	42	47
	13	1	2	3	4	8	12	16	21	25	30	34	39	44
	15	1	2	2	4	7	11	15	19	23	27	31	36	40
	17	1	1	2	3	6	10	13	17	20	24	28	31	35
	19	1	1	2	3	5	8	11	14	16	19	23	26	29
	21	1	1	1	2	4	6	8	10	12	14	16	18	21
	23	<1	<1	1	1	2	3	4	5	6	7	8	9	9

FLAME ft		**Effective Windspeed(EWS), mph** *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	4	5	6	8	10	12	14	16	17	19	20	21	22
	3	3	4	5	7	9	11	12	14	15	16	17	18	19
	5	3	4	5	6	8	9	11	12	13	14	15	16	17
	7	3	4	4	5	7	9	10	11	12	13	14	15	16
	9	3	3	4	5	7	8	9	10	11	12	13	14	15
	11	3	3	4	5	6	8	9	10	11	12	13	13	14
	13	2	3	4	5	6	7	9	10	10	11	12	13	14
	15	2	3	3	4	6	7	8	9	10	11	11	12	13
	17	2	3	3	4	5	6	7	8	9	10	10	11	12
	19	2	2	3	3	5	5	6	7	8	8	9	9	10
	21	1	2	2	3	3	4	5	5	6	6	7	7	7
	23	1	1	1	1	2	2	2	3	3	3	3	4	4

5.3.13 Fuel Model 13 (Heavy Logging Slash)

Fire is generally carried across the area by a continuous layer of slash. Large quantities of heavy fuels are present. Fires spread quickly through the fine fuels and intensity builds up more slowly as the large fuels start burning. Active flaming supports a wide variety of firebrands, contributing to spotting problems. The total load may exceed 200 tons per acre (89.2 t/ha) but fine fuels generally only 10 percent of the total load. Situations where the slash still has “red” needles attached but the total load is lighter can be represented because of the earlier high intensity and quicker area involvement.

SPREAD Ch/hr		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.5)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	4	8	12	16	20	24	28	32	36	40
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	3	5	6	11	20	30	41	52	63	75	86	98	111
	3	2	4	5	9	16	25	34	43	52	61	71	81	91
	5	2	3	5	7	14	21	28	36	44	52	60	69	77
	7	2	3	4	6	12	18	25	31	38	45	52	60	67
	9	2	2	4	6	11	16	22	28	34	41	47	54	60
	11	1	2	3	5	10	15	20	26	32	37	43	49	55
	13	1	2	3	5	9	14	19	24	29	35	40	46	51
	15	1	2	3	5	9	13	18	23	27	33	38	43	48
	17	1	2	3	4	8	12	17	21	26	30	35	40	45
	19	1	2	2	4	8	11	15	19	24	28	32	37	42
	21	1	2	2	4	7	10	14	18	21	25	29	33	37
	23	1	1	2	3	6	9	12	15	18	22	25	29	32
	25	1	1	2	3	5	7	10	12	15	18	21	23	26
	27	1	1	1	2	3	5	7	9	11	13	15	17	19
	29	<1	<1	<1	1	2	3	4	5	6	7	8	9	10

FLAME feet		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.5)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	4	8	12	16	20	24	28	32	36	40
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	5	7	8	10	13	16	18	20	22	24	26	27	29
	3	5	6	7	9	11	14	16	18	19	21	22	24	25
	5	4	5	6	8	10	12	14	16	17	19	20	21	22
	7	4	5	5	7	9	11	13	14	16	17	18	19	20
	9	4	4	5	6	9	10	12	13	15	16	17	18	19
	11	3	4	5	6	8	10	11	13	14	15	16	17	18
	13	3	4	5	6	8	9	11	12	13	14	15	16	17
	15	3	4	5	6	8	9	10	12	13	14	15	16	17
	17	3	4	4	5	7	9	10	11	12	13	14	15	16
	19	3	3	4	5	7	8	10	11	12	13	13	14	15
	21	3	3	4	5	6	8	9	10	11	12	13	13	14
	23	2	3	3	4	6	7	8	9	10	10	11	12	13
	25	2	2	3	4	5	6	7	7	8	9	9	10	11
	27	2	2	2	3	4	4	5	6	6	7	7	8	8
	29	1	1	1	2	2	2	3	3	3	4	4	4	4

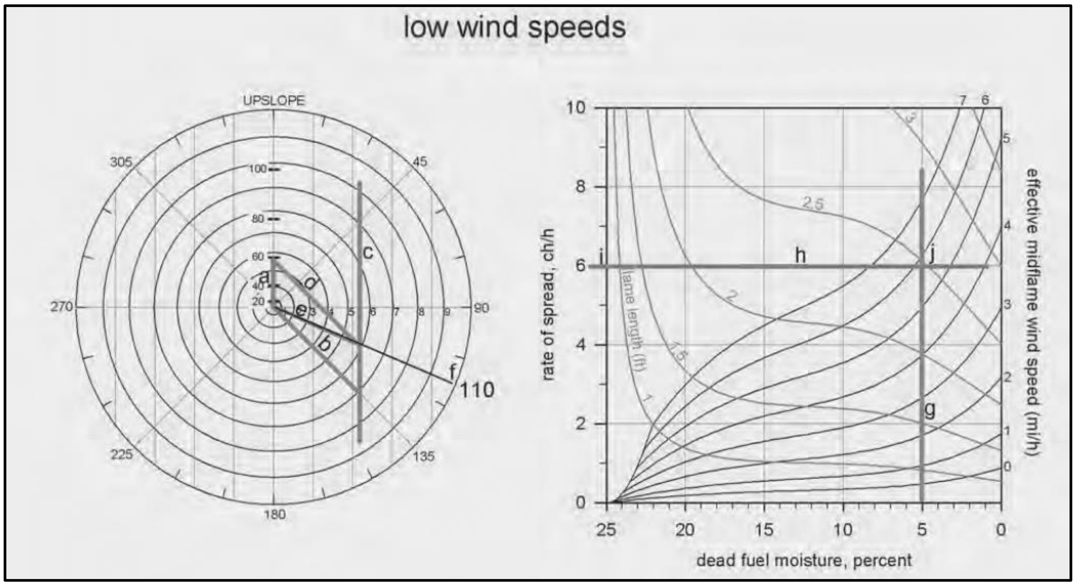
5.4 Surface Fire Behavior Nomograms & Nomographs

5.4.1 Instructions for Nomograph Use (Scott 2007)

Reference: http://www.fs.fed.us/rm/pubs/rmrs_gtr192.pdf

Each fuel model includes a duplicate set of effective windspeed protractor and fire behavior nomograph, one for low wind speeds and one for high wind speeds. Select the one with applicable windspeeds.

Example Nomograph



Inputs Required

1. Fuel Model
2. Midflame Windspeed and direction, azimuth clockwise from upslope
3. Slope %
4. Dead and Live Fuel Moistures.

Determine Effective Windspeed (EWS) - low or high

Use the left side nomograph, shown above, if the situation includes cross slope winds

1. Plot the slope vector (a) in the upslope direction to the hash representing the slope %. Interpolate if necessary
2. Plot the wind vector (b) using the concentric circle to for the input windspeed and the azimuth above for direction.
3. Plot parallel vectors (c & d) and resultant vector (e). Read resulting windspeed (e) & direction (f).

Estimate Head Fire Rate of Spread & Flame Length

If the fuel model includes a live fuel component, use the nomograph that references the appropriate live fuel moisture. Otherwise, there is only one nomograph, shown on right.

1. Using the input dead fuel moisture, draw vertical line (g) to the estimated EWS curve.
2. Read the flame length from the embedded curves at the intersection (j). Interpolate between lines if necessary.
3. Draw horizontal line (h) to the left axis and read the Rate of Spread at intersection (i)

5.4.2 Instructions for Nomogram Use (Rothermel 1983)

Reference: https://www.fs.fed.us/rm/pubs_int/int_gtr143.pdf

Nomograms: https://www.frames.gov/catalog/8137

Unlike the newer Nomographs, the original surface fire behavior nomograms have several limitations:

- These Nomograms are only available for the original 13 fuel models.
- They are intended for use with wind blowing within ±30 degrees of upslope. Use in vectoring is possible, though it is not outlined here.

Inputs required,

1. fuel model,
2. midflame windspeed,
3. percent slope,
4. dead fuel moisture (use 1-hr), and
5. live fuel moisture for fuel models 2, 4, 5, 7, & 10.

Select the appropriate windspeed (Low/High) nomogram.

The numbered steps below correspond to the labeled lines on the example nomograms.

Part I: Estimate Effective Windspeed (for all fuel models)

1. In lower left quadrant, draw vertical line from percent slope value to intersect midflame windspeed curve. Draw horizontal line to left axis and read effective windspeed.
2. In lower right quadrant, *identify and highlight the appropriate effective windspeed line*. Interpolate by adding line for effective windspeed from 1 above if it is between existing lines.

Part II: Fuel Moisture

For FM 1, 3, 6, 8, 9, 11, 12, 13 with only dead fuel

3. In the upper left quadrant of the nomogram, *identify and highlight the appropriate dead fuel moisture line* based on the input value provided. Interpolate by drawing new line between existing lines if necessary.

For FM 2, 4, 5, 7, 10 with live fuel

3a. Using the two upper quadrants, locate the appropriate dead fuel moisture value on the two outer vertical axes (highlighted) Connect with a horizontal line.
3b. Connect the point where the horizontal line intersects the live fuel curve in the upper left quadrant to the origin point, creating a straight line.
3c. Using the input live fuel moisture provided, identify and highlight the appropriate S-curve in the upper right quadrant. Interpolate by adding a new line between existing lines if necessary.

At this point, turning lines have been identified in all 4 quadrants (including the S-curve in the upper right quadrant and the default corner to corner line in the lower left). The Nomogram is prepared for Part III.

Part III: Estimating Fire Behavior

With the preparations in parts I and II, "turning" lines have been highlighted in the lower right quadrant and the upper left quadrant, as well as the appropriate S-curve in the upper right quadrant for fuel models with live fuels.

4a. Begin in the upper right quadrant. Draw horizontal line from dead fuel moisture to the highlighted fuel moisture turning line (s-curve),

4b. From intersection, draw vertical line down to the turning line in the lower right quadrant (highlighted in step 2).

5. From intersection with turning line in the lower right, draw horizontal line to the turning line in the lower left quadrant.
6. From intersection with the turning line in the lower left quadrant, draw vertical line up to the turning line in the upper left quadrant (highlighted in step 3).
7. From intersection with turning line in the upper left quadrant, draw horizontal line to the right until it intersects the vertical line drawn in step 4.

Part IV: Reading Fire Behavior Outputs

Read *Heat Per Unit Area* where vertical line from step 2 intersects its axis in the upper right quadrant.

- In the first example (Dead Fuel Only), the Heat Per Unit Area is estimated at approximately **750 BTU/sq. ft**.
- In the second example (Dead & Live Fuels), the Heat Per Unit Area is estimated at approximately **215 BTU/sq. ft**.

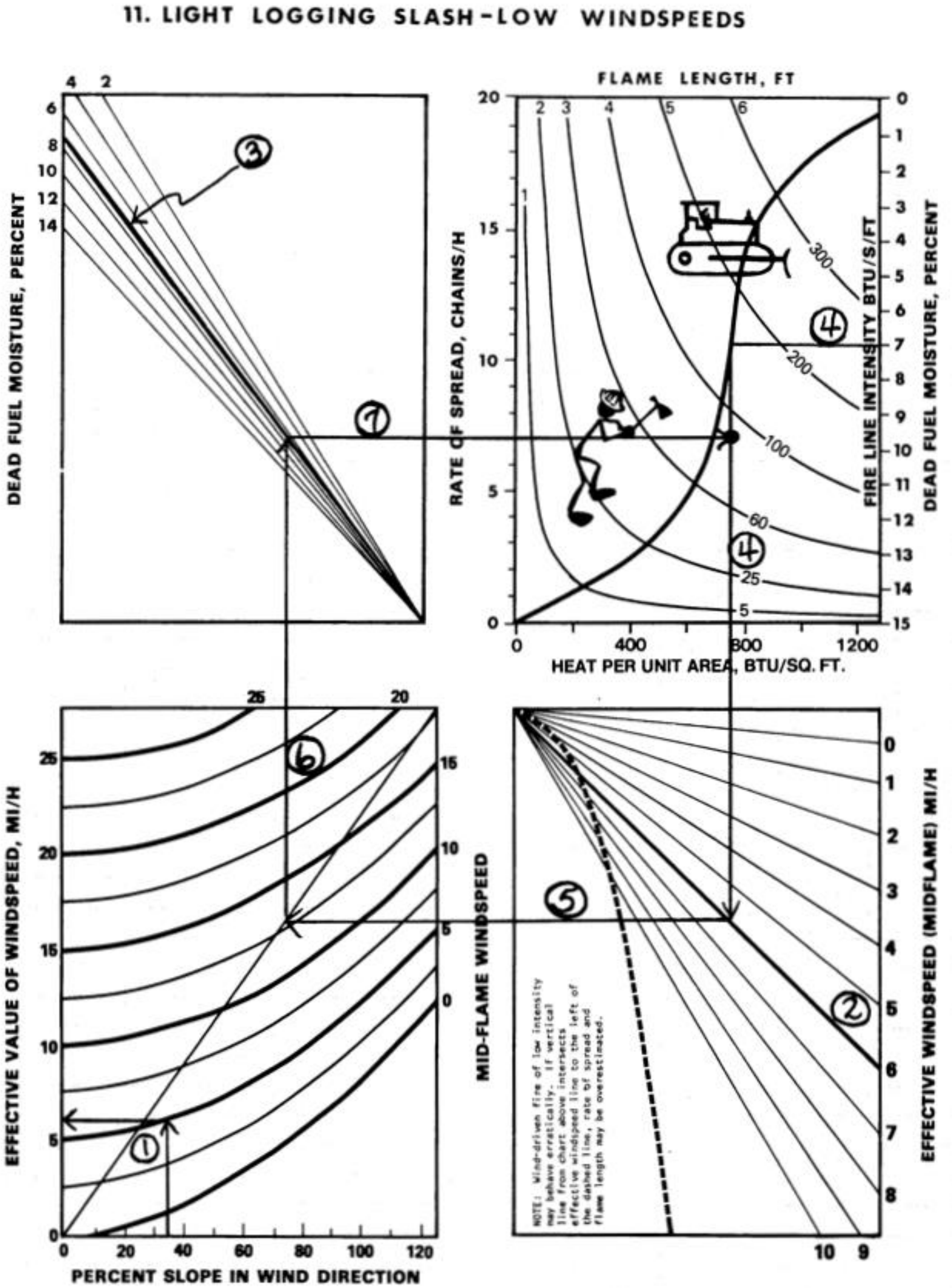
Read *Rate of Spread* where horizontal line from step 5 intersects its axis in the upper right quadrant.

- In the first example (Dead Fuel Only), the Rate of Spread is estimated at approximately **7 chains per hour**.
- In the second example (Dead & Live Fuels), the Rate of Spread is also estimated at approximately **7 chains per hour**.

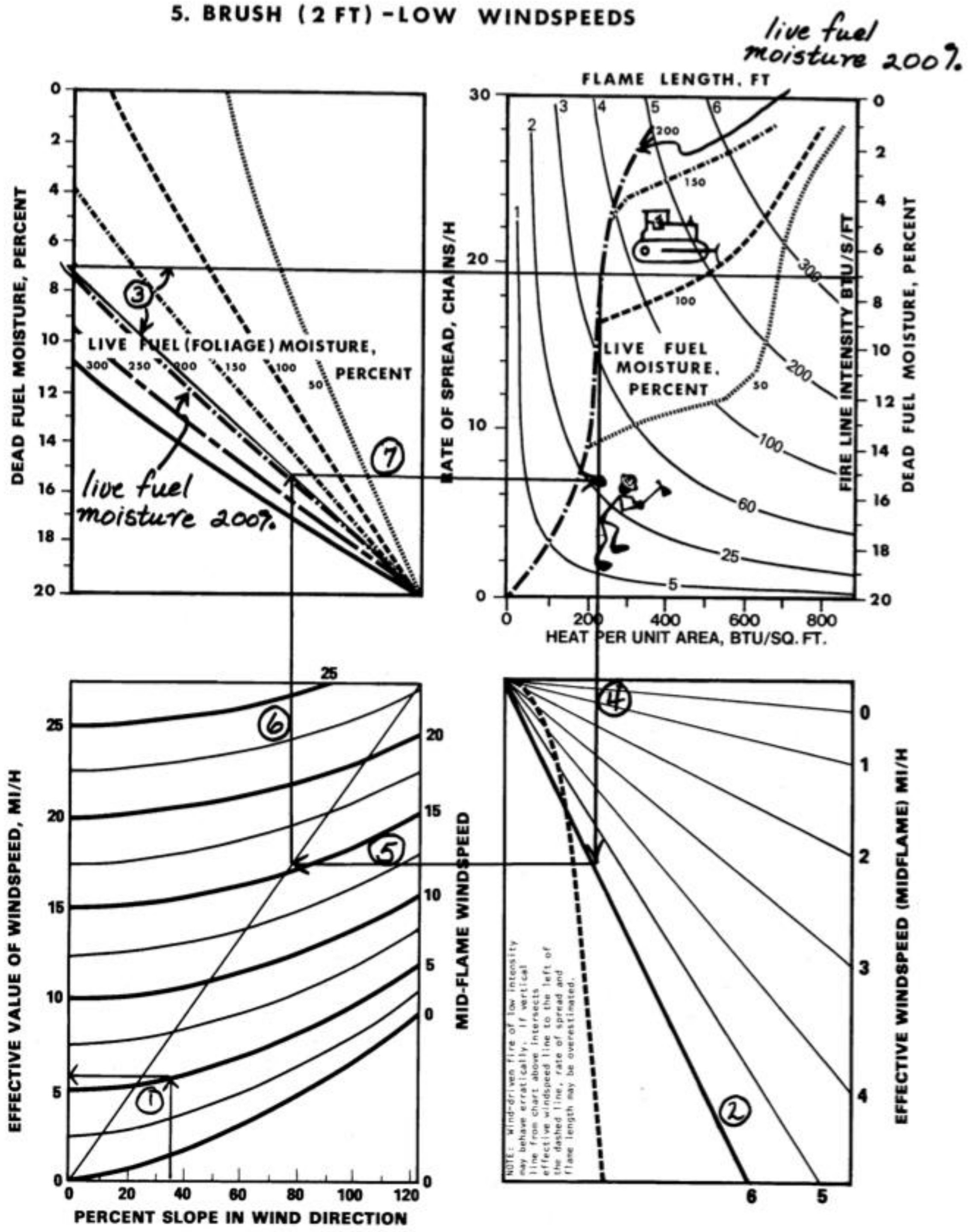
Read Flame Length and Fireline Intensity at the final intersection produced in step 5.

- In the first example (Dead Fuel Only), the intersection between lines 4 and 7 comes between the Flame Length/Fireline Intensity contour lines 3/60 and 4/100. It could be estimated as **4 ft or 90 BTU/ft/sec**
- In the second example (Dead & Live Fuels), the intersection between lines 4 and 7 comes between the Flame Length/Fireline Intensity contour lines 2/25 and 3/60. It could be estimated as **2 ft or 30 BTU/ft/sec**

Example Nomogram for Dead Fuel Only (Fuel Models 1, 3, 6, 8, 9, 11, 12, 13)



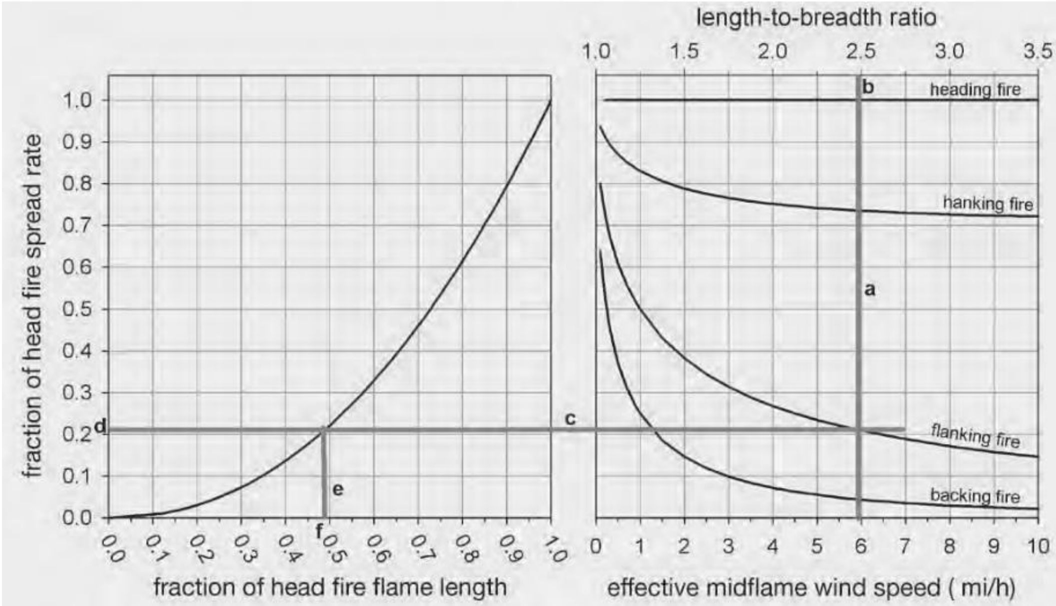
Example Nomogram Using Dead & Live Fuels (Fuel Models 2, 4, 5, 7, 100



5.5 Flanking and Backing Fire Behavior

The tables and nomographs produce good estimates of head fire behavior.

This nomograph uses effective windspeed to produce adjustment factors for both spread rate and flame length that can be applied to the head fire behavior outputs.



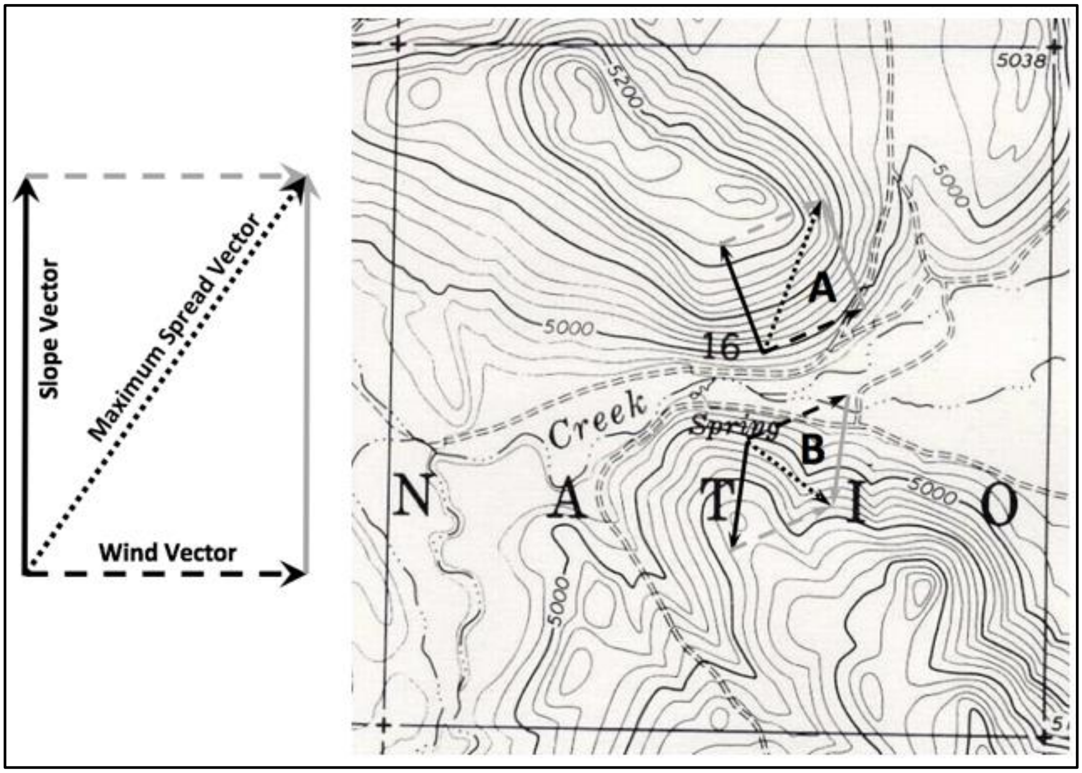
Procedure:

1. Begin with the EWS at the base of the right-hand chart, draw vertical line to intersect desired spread direction and the axis at top to read the length to breadth ratio.
2. Draw horizontal line from intersection at desired spread direction into and across the left-hand chart to intersect the left axis. Read the fraction from left axis and apply it to the headfire ROS to obtain the spread rate in the assumed direction.
3. Draw vertical line down from where horizontal line intersected curve in left hand chart to bottom axis. Read the fraction from this bottom axis and apply it to the headfire flame length estimate to obtain the flame length in the spread direction assumed.

5.6 Vectoring Fire Behavior (Cross Slope Winds)

Projecting fire spread with cross slope winds utilizes a vectoring process, where the effect of wind and the effect of slope on Rate of Spread (ROS) may be represented by separate vectors that represent both a magnitude and a direction. The resultant vector represents both a direction and magnitude of maximum spread in that direction

1. Slope Vector is drawn directly upslope and estimated by calculating ROS with the estimated slope steepness and Zero (0) windspeed for inputs.
2. Wind Vector is drawn in the direction of the wind and estimated by calculating ROS with the estimated windspeed and Zero (0) slope.
3. Maximum Spread Vector can be drawn as shown and measured to determine the resultant ROS and spread direction



In example **A** here, wind is crossing more upslope, resulting in an enhanced maximum ROS.

In example **B**, wind is crossing more downslope, resulting in a reduced maximum ROS.

With winds blowing downslope (±30°), the difference between the spread rates is the resulting ROS using the direction from the larger vector.

If the vectoring process is completed manually, fireline intensity (FLI) and flame length (FL) can be calculated from ROS and Heat Per Unit Area (HPA) using these calculations

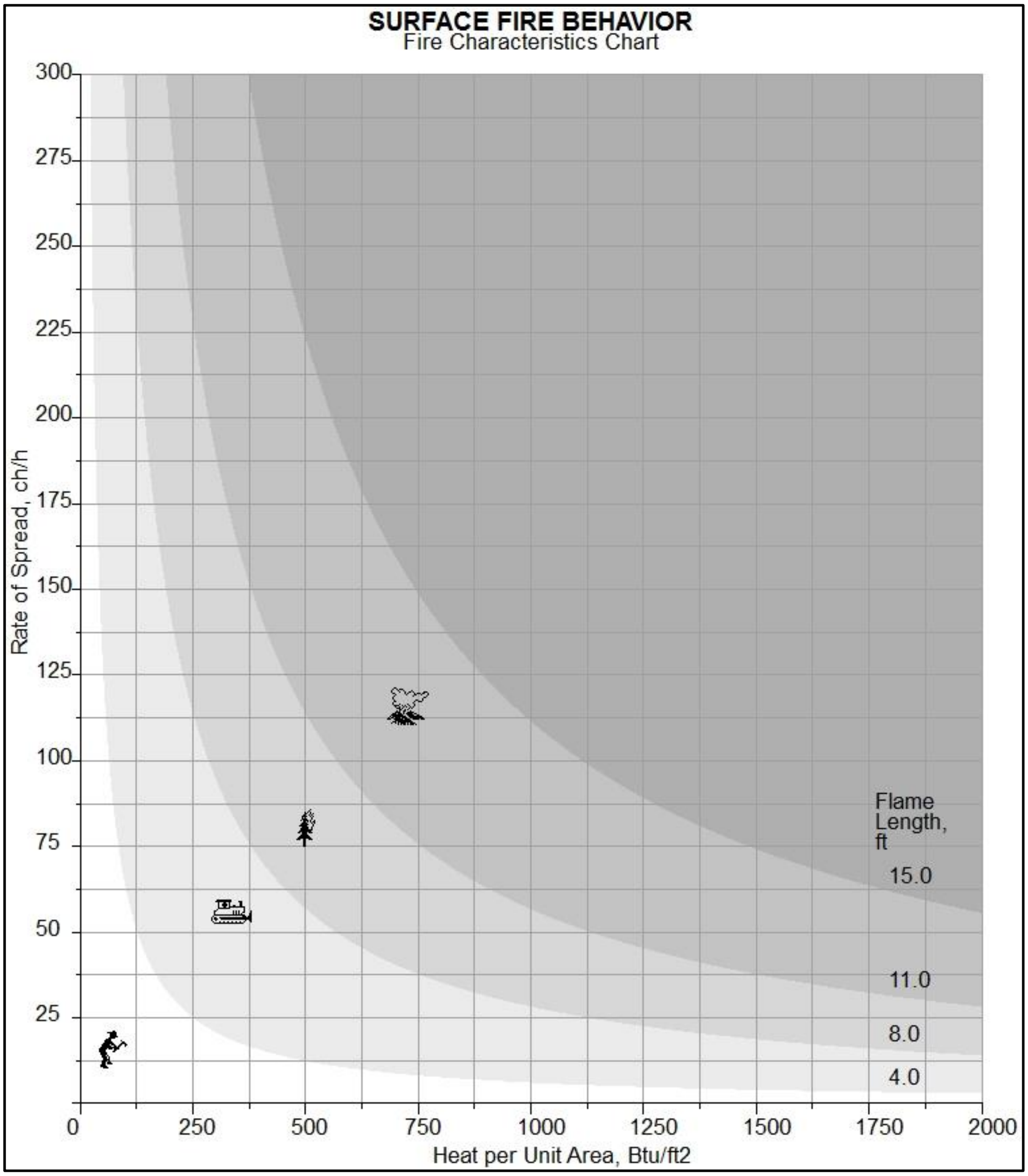
$$FLI = (ROS * HPA)/55$$

$$FL = .45 * FLI^{.46}$$

5.7 Interpreting Expected Surface Fire Behavior

Once estimates of Rate of Spread and Flame Length have been obtained, use these classifications to evaluate the level of concern they generate.

Fire Behavior Class	Rate of Spread (ch/hr)	Flame Length (ft)	Tactical Interpretation
Very Low	0-2	0-1	Direct, Hand
Low	2-5	1-4	Direct, Hand
Moderate	5-20	4-8	Direct, Equip
High	20-50	8-12	Indirect
Very High	50-150	12-25	Indirect
Extreme	150+	25+	Indirect



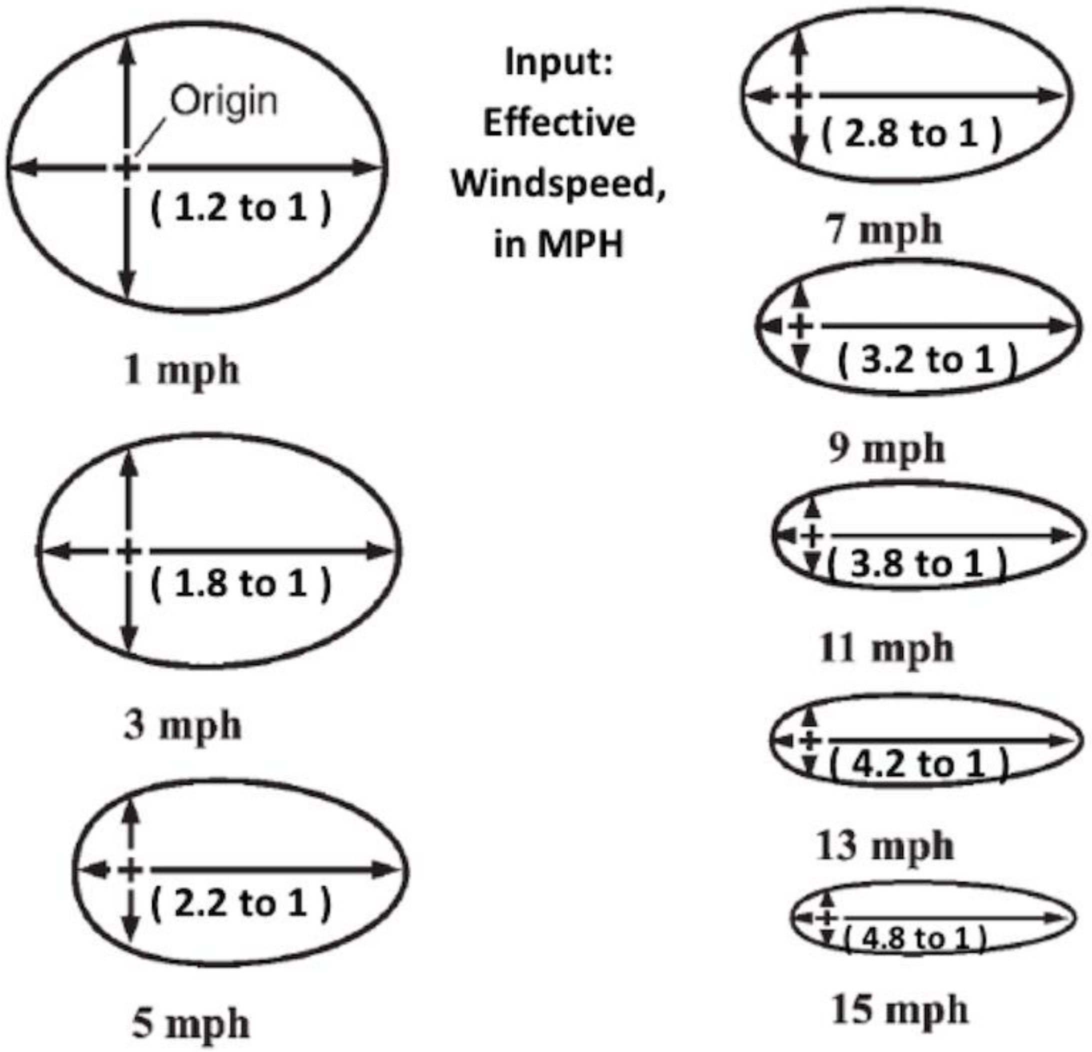
5.8 Surface Fire Size and Shape

These tools are intended for use with initiating fires only. Use them using the known ignition time and the number of hours after that you are interested in. Consider using:

- number of hours from ignition until the end of the expected burn period
- number of hours until you arrive at the fire

5.8.1 Surface Fire Shape

Length to width ratio in parenthesis



5.8.2 Surface Fire Area Estimation from a Point Source Fire in Acres

Spread Distance, in Chains	Effective Windspeed, in mph									
	1	3	5	7	9	11	13	15	17	19
	Acres									
1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.4	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
3	1	1	0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.1
4	2	1	1	1	0.4	0.3	0.3	0.3	0.2	0.2
5	3	1	1	1	1	1	1	0.4	0.4	0.3
6	4	2	1	1	1	1	1	1	1	1
7	5	3	2	2	1	1	1	1	1	1
8	6	4	3	2	2	1	1	1	1	1
9	8	4	3	3	2	2	2	1	1	1
10	10	5	4	3	3	2	2	2	2	1
11	12	7	5	4	3	3	2	2	2	2
12	14	8	6	4	4	3	3	2	2	2
13	17	9	7	5	4	4	3	3	3	2
14	19	11	8	6	5	4	4	3	3	3
15	22	12	9	7	6	5	4	4	3	3
16	25	14	10	8	7	6	5	4	4	4
17	28	16	11	9	7	6	6	5	4	4
18	32	18	13	10	8	7	6	6	5	5
19	35	20	14	11	9	8	7	6	6	5
20	39	22	16	12	10	9	8	7	6	6
21	43	24	17	14	11	10	8	8	7	6
22	48	26	19	15	12	11	9	8	7	7
23	52	29	21	16	13	12	10	9	8	7
24	57	31	22	18	15	13	11	10	9	8
25	61	34	24	19	16	14	12	11	10	9
26	66	37	26	21	17	15	13	11	10	9
28	77	43	31	24	20	17	15	13	12	11
30	88	49	35	28	23	20	17	15	14	13
32	101	56	40	31	26	22	20	17	16	14
34	114	63	45	35	29	25	22	20	18	16
36	127	70	50	40	33	28	25	22	20	18
38	142	78	56	44	37	31	28	24	22	20
40	157	87	62	49	41	35	30	27	24	22
42	173	96	69	54	45	38	34	30	27	25
44	190	105	75	59	49	42	37	33	30	27
46	208	115	82	65	54	46	40	36	32	29
48	226	125	90	71	59	50	44	39	35	32
50	245	135	97	77	64	54	48	42	38	35

Spread Distance, in Chains	Effective Windspeed, in mph									
	1	3	5	7	9	11	13	15	17	19
	Acres									
52	266	146	105	83	69	59	51	46	41	38
54	286	158	113	89	74	63	55	49	44	40
56	308	170	122	96	80	68	60	53	48	44
58	330	182	131	103	85	73	64	57	51	47
60	353	195	140	110	91	78	68	61	55	50
62	377	208	149	118	98	84	73	65	59	53
64	402	222	159	125	104	89	78	69	62	57
66	428	236	169	133	111	95	83	74	66	60
68	454	250	180	142	117	100	88	78	71	64
70	481	265	190	150	124	106	93	83	75	68
72	509	281	201	159	132	113	99	88	79	72
74	538	297	213	168	139	119	104	93	83	76
76	567	313	224	177	147	126	110	98	88	80
78	597	330	236	186	154	132	116	103	93	84
80	628	347	249	196	162	139	122	108	98	89
82	660	364	261	206	171	146	128	114	103	93
84	693	382	274	216	179	153	134	119	108	98
86	726	401	287	227	188	161	141	125	113	103
88	760	419	301	237	197	168	147	131	118	107
90	795	439	315	248	206	176	154	137	123	112
92	831	458	329	259	215	184	161	143	129	117
94	868	479	343	271	224	192	168	149	135	123
96	905	499	358	282	234	200	175	156	140	128
98	943	520	373	294	244	209	183	162	146	133
100	982	542	389	306	254	217	190	169	152	139
105	1082	597	428	338	280	240	210	187	168	153
110	1188	655	470	371	307	263	230	205	184	168
115	1298	716	514	405	336	287	251	224	202	183
120	1414	780	559	441	366	313	274	244	219	200
125	1534	846	607	478	397	339	297	264	238	217
130	1659	915	657	518	429	367	321	286	258	234
135	1789	987	708	558	463	396	347	308	278	253
140	1924	1062	761	600	498	426	373	332	299	272
145	2064	1139	817	644	534	457	400	356	320	292
150	2209	1219	874	689	571	489	428	381	343	312
155	2359	1301	933	736	610	522	457	406	366	333
160	2513	1386	995	784	650	556	487	433	390	355
165	2673	1474	1058	834	691	591	518	460	415	378

5.8.3 Surface Fire Perimeter Estimation from a Point Source Fire in Acres

Spread Distance, in Chains	Effective Windspeed, in mph									
	1	3	5	7	9	11	13	15	17	19
	Chains									
1	4	3	2	2	2	2	2	2	2	2
2	7	6	5	5	5	4	4	4	4	4
3	11	8	7	7	7	7	6	6	6	6
4	14	11	10	9	9	9	9	9	8	8
5	18	14	12	12	11	11	11	11	11	10
6	21	17	15	14	14	13	13	13	13	13
7	25	19	17	16	16	15	15	15	15	15
8	28	22	20	19	18	18	17	17	17	17
9	32	25	22	21	20	20	19	19	19	19
10	35	28	25	23	23	22	22	21	21	21
11	39	30	27	26	25	24	24	23	23	23
12	43	33	30	28	27	26	26	26	25	25
13	46	36	32	30	29	29	28	28	27	27
14	50	39	35	33	32	31	30	30	30	29
15	53	41	37	35	34	33	32	32	32	31
16	57	44	40	37	36	35	35	34	34	34
17	60	47	42	40	38	37	37	36	36	36
18	64	50	45	42	41	40	39	38	38	38
19	67	52	47	44	43	42	41	41	40	40
20	71	55	50	47	45	44	43	43	42	42
21	74	58	52	49	47	46	45	45	44	44
22	78	61	55	51	50	48	48	47	46	46
23	82	64	57	54	52	51	50	49	49	48
24	85	66	60	56	54	53	52	51	51	50
25	89	69	62	59	56	55	54	53	53	52
26	92	72	65	61	59	57	56	55	55	54
28	99	77	70	66	63	62	61	60	59	59
30	106	83	74	70	68	66	65	64	63	63
32	113	88	79	75	72	70	69	68	68	67
34	121	94	84	80	77	75	73	73	72	71
36	128	99	89	84	81	79	78	77	76	75
38	135	105	94	89	86	84	82	81	80	80
40	142	110	99	94	90	88	86	85	84	84
42	149	116	104	98	95	92	91	90	89	88
44	156	122	109	103	99	97	95	94	93	92
46	163	127	114	108	104	101	99	98	97	96
48	170	133	119	112	108	106	104	102	101	101
50	177	138	124	117	113	110	108	107	106	105

Spread Distance, in Chains	Effective Windspeed, in mph									
	1	3	5	7	9	11	13	15	17	19
	Chains									
52	184	144	129	122	117	114	112	111	110	109
54	191	149	134	126	122	119	117	115	114	113
56	199	155	139	131	126	123	121	119	118	117
58	206	160	144	136	131	128	125	124	122	122
60	213	166	149	140	135	132	130	128	127	126
62	220	171	154	145	140	136	134	132	131	130
64	227	177	159	150	144	141	138	137	135	134
66	234	182	164	154	149	145	143	141	139	138
68	241	188	169	159	153	150	147	145	144	142
70	248	193	174	164	158	154	151	149	148	147
72	255	199	179	169	162	158	156	154	152	151
74	262	204	184	173	167	163	160	158	156	155
76	269	210	189	178	171	167	164	162	160	159
78	277	215	194	183	176	172	169	166	165	163
80	284	221	199	187	180	176	173	171	169	168
82	291	227	204	192	185	180	177	175	173	172
84	298	232	209	197	189	185	182	179	177	176
86	305	238	214	201	194	189	186	183	182	180
88	312	243	219	206	198	194	190	188	186	184
90	319	249	223	211	203	198	194	192	190	189
92	326	254	228	215	207	202	199	196	194	193
94	333	260	233	220	212	207	203	200	199	197
96	340	265	238	225	217	211	207	205	203	201
98	347	271	243	229	221	216	212	209	207	205
100	355	276	248	234	226	220	216	213	211	210
105	372	290	261	246	237	231	227	224	222	220
110	390	304	273	257	248	242	238	235	232	230
115	408	318	286	269	259	253	249	245	243	241
120	425	331	298	281	271	264	259	256	253	251
125	443	345	310	293	282	275	270	267	264	262
130	461	359	323	304	293	286	281	277	275	272
135	479	373	335	316	304	297	292	288	285	283
140	496	387	348	328	316	308	303	299	296	293
145	514	401	360	339	327	319	313	309	306	304
150	532	414	372	351	338	330	324	320	317	314
155	550	428	385	363	350	341	335	331	327	325
160	567	442	397	374	361	352	346	341	338	335
165	585	456	410	386	372	363	357	352	348	346

5.9 References

Andrews, P. L.; Heinsch, F. A.; Schelvan, L. 2011. How to generate and interpret fire characteristics charts for surface and crown fire behavior. General Technical Report RMRS-GTR-253. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 40p.

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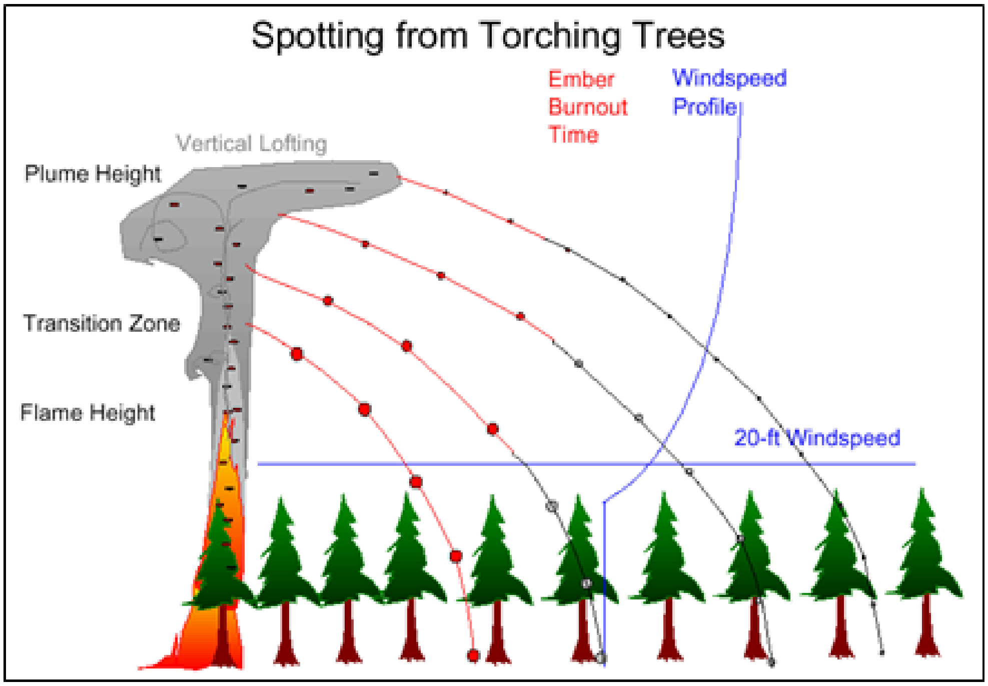
6. Crown Fire Behavior

6.1 Spotting Fire Behavior

Evaluating spotting fire behavior requires the integration of three factors:

- the source, size, and number of firebrands
- the distance the firebrand is carried downwind
- the probability of igniting a new fire at the downwind location.



Short-Range Spotting is not generally considered as significant in the growth if wildfires, because the advancing fire usually overruns the developing spot fire.

Long-Range Spotting is differentiated from short-range spotting, primarily because firebrands are being lofted by a convection column and carried beyond the immediate fire area.

6.1.1 Estimating Maximum Spotting Distance

Quick Reference Maximum Spotting Distance Table (under const.)

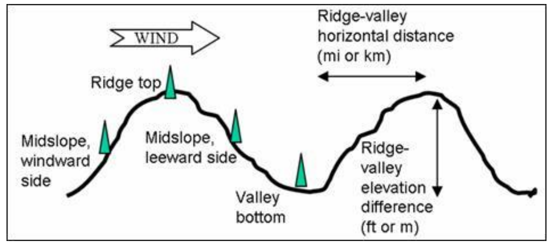
Both the included Spotting Distance Nomograms (with the associated worksheet in Section 5.5) and BehavePlus provide methods for estimating the Maximum Spotting Distance from a Torching Tree, or trees.

The maximum spotting distance model requires identification of ***tree species, height, and DBH*** of the torching tree to estimate the flame height and duration from the torching tree that will initiate the lofting of the ember into the windfield.

Further, the ***open windspeed*** is used to suggest how far the fire brand will be transported as it falls back to the ground. The nomogram, because it assumes level ground uses the surface (20ft) windspeed and direction.

The ***downwind Canopy, or Tree Cover, Height*** (reduced by half for open canopies) is used to factor out embers intercepted by the canopy before reaching surface fuels.

The graphic here depicts additional inputs to the BehavePlus spotting module. In mountainous terrain, ridge top winds are used if wind is blowing across valleys as shown. The shape of the valley is considered with inputs for ***Ridge-to-Valley distance*** and ***elevation difference***.



Maximum Spotting Distance Nomogram Instructions

Inputs Required:

- Torching Tree: Species, Height, DBH
- Open 20 ft Windspeed
- Downwind Average Tree Height (Divide by 2 for open stands)

Nomogram 1 (Flame Height) & Nomogram 2 (Flame Duration)

Start with input DBH, draw vertical line to interest curve for input torching tree species, turn and draw horizontal line to determine flame height in Nomogram 1 and flame duration in Nomogram 2

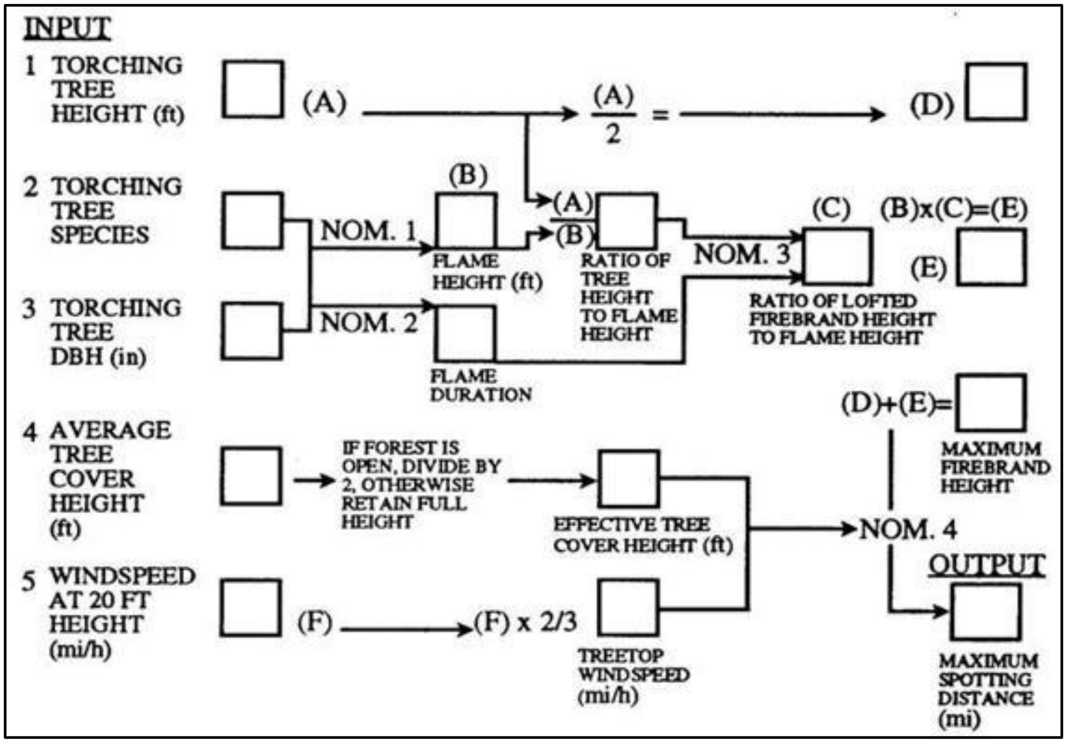
Nomogram 3 (Firebrand Lofting):

Divide Flame Height (Nom 1) by the input torching tree height and use that value to select the curve in Nom 3. Using the flame duration (Nom 2), draw a vertical line from the bottom axis to intersect the selected curve. From that intersection, draw a horizontal line to determine ratio for calculating firebrand height. Multiply ratio from Nom 3 by flame height to determine firebrand height.

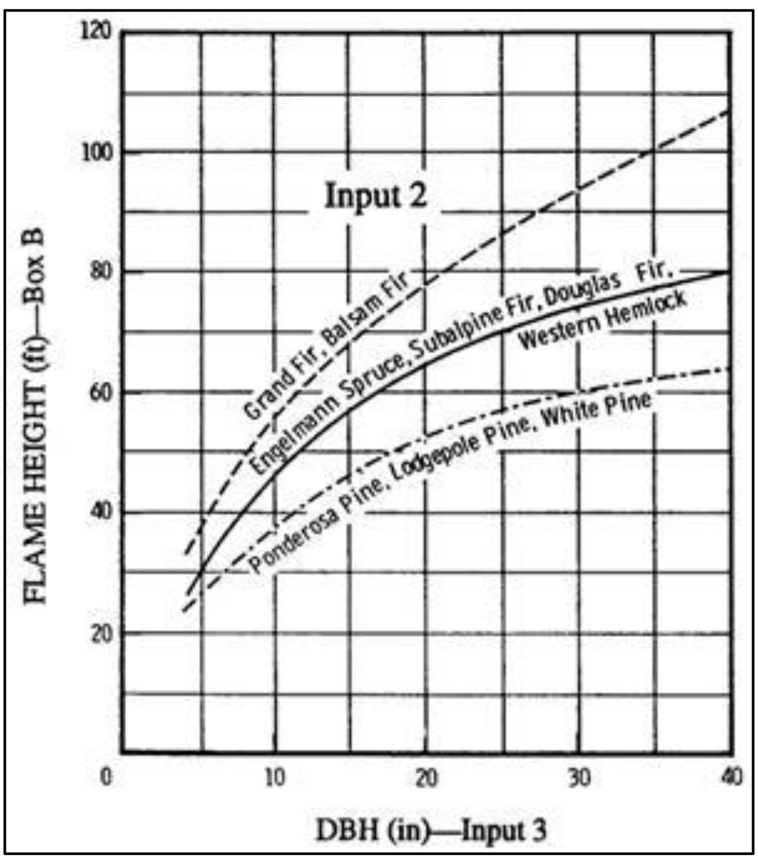
Nomogram 4 (Maximum Spotting Distance):

Using the estimated firebrand ht., draw vertical line from bottom axis on right to intersect curve for selected downwind tree ht. From intersection draw horizontal line to line for input windspeed, then down to spot distance.

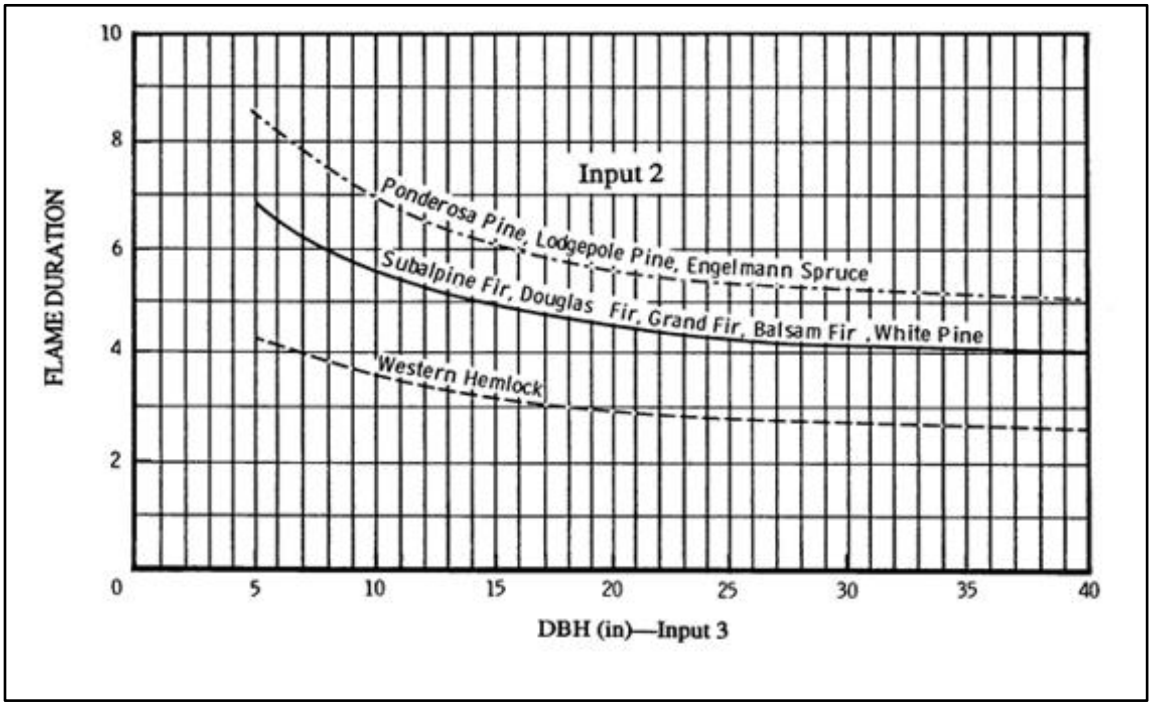
Nomogram Worksheet (follow 1 to 5, left to right on each line)



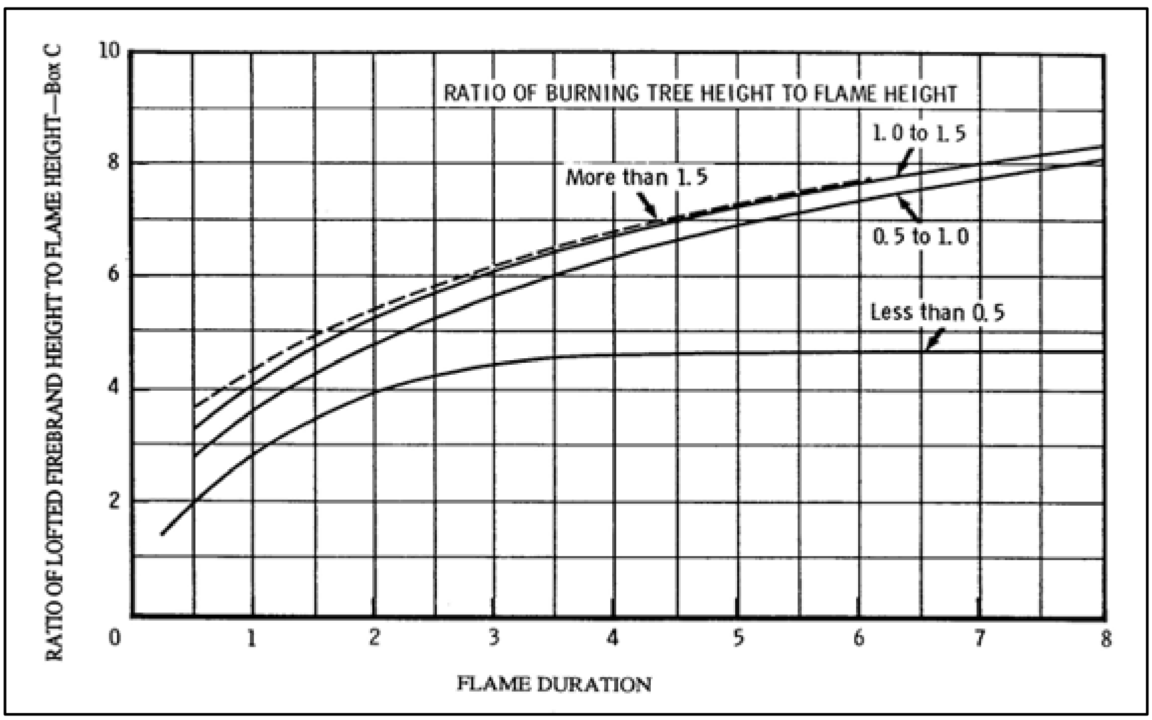
Nomogram 1. Flame Height



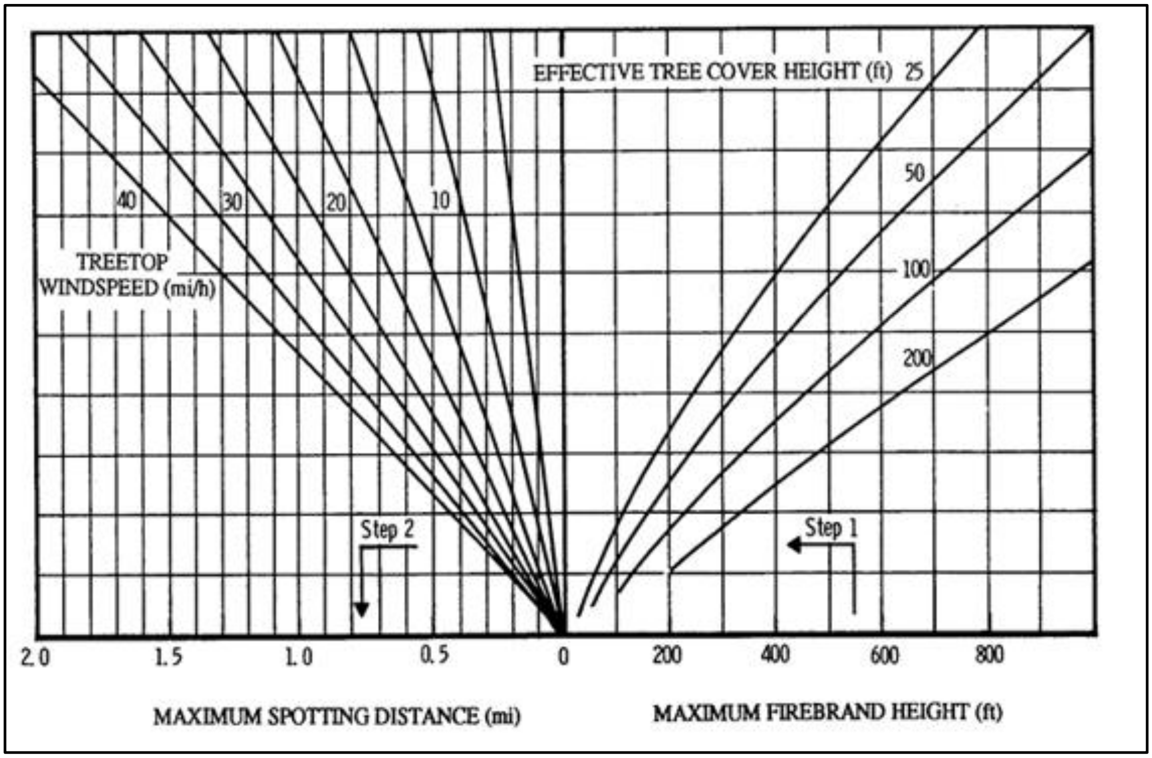
Nomogram 2. Flame Duration



Nomogram 3. Firebrand Lofting



Nomogram 4. Maximum Spotting Distance



6.1.2 Spotting Likelihood/Probability

Though tables for Probabilty of Ignition are provided in the Fuel Moisture section, they describe only the likelihood that an ember will ignite a fire in receptive fuels. WFDSS spatial analyses integrate the potential frequency and distance for spotting fire behavior, but frequency information is hard to isolate.

Tonja Opperman suggested a method for applying the WFDSS spotting models to isolate the potential probability of spotting across significant barriers using FSPro analysis.

6.1.3 Integrating Spotting Spread into Fire Growth Projections

FARSITE, FLAMMAP, and FSPro attempt to integrate the estimate of the number of embers and the distribution of distances they travel into the fire growth projection. Estimating maximum spotting distance from nomograms or BehavePlus only suggests an outer perimeter for spotting potential.

6.1.4 Comparing Spotting Estimation Tools

Tonja Opperman, Fire Applications Specialist, Wildland Fire Management RD&A, assembled these tables based on contributions and discussions among many fire behavior researchers, programmers, and practitioners, including: Pat Andrews, Mark Finney, and Chuck McHugh at the Missoula Fire Lab; Brian Sorbel from the Alaska Region of the NPS; Mitch Burgard and Erin Noonan-Wright from the Wildland Fire Management RD&A; Stu Brittain with Systems for Environmental Management in Missoula; Joe Scott with Pyrologix in Missoula; and Rick Stratton from the Pacific Northwest Region of the USFS. Corrections can be forwarded to Tonja Opperman at tonja_opperman@firenet.gov.

<u>Maximum Spotting Distance</u>

System	Maximum Spotting Distance from Torching Trees Nomograms (Non-spatial)	BehavePlus v.5.0.5 (Non-spatial)
Inputs	• Torching tree height • Torching tree species • Torching tree DBH • Average tree height • 20-foot wind speed	• Torching tree height • Torching tree species • Torching tree DBH • Downwind canopy height • 20-ft wind speed • Number of torching trees • Ridge/Valley elevation difference • Ridge/Valley horizontal distance • Spotting source location
Spotting Process	Nomograms published in Rothermel (1983) are based on the model published by Albini (1979). Predictive mathematical model to calculate the maximum distance an ember will travel from a single firebrand is lofted from a torching tree to calculate maximum distance.	Spotting from torching trees is based on nomograms with options for multiple torching trees and terrain adjustment (Albini 1979, Chase 1981, Rothermel 1983). BehavePlus also calculates spotting from wind-driven surface fire (Albini 1983, Chase 1984, Morris 1987) and spotting from burning piles (Albini 1981). *Spotting from active crown fire will be added in BehavePlus v6.0 (Albini et al. 2012).*
Outputs	Maximum spotting distance from a single torching tree on flat ground is read from a nomogram.	Maximum spotting distance from torching trees (single or multiple) is displayed in a table and graph. Probability of ignition is calculated separately.
Assumptions & Limitations	Gives maximum distance only. Assumes level terrain; single torching tree. Does not account for likelihood of trees torching, firebrand material availability, the number of spot fires, or the probability of ignition for that firebrand.	Gives maximum distance only. Accounts for terrain and number of torching trees. Number of torching trees is used to calculate firebrand lofting height; higher firebrands travel further, all else equal. Does not account for likelihood of trees torching, firebrand material availability, or the number of spot fires, or the probability of ignition for that firebrand

WFDSS Spotting Spread

In all geospatial systems, embers are only generated from passive and active crown fires, not from surface fires, fire whirls, burning piles, or structures. Spotting can be turned off or set to zero in all tools.

System	Short Term Fire Behavior (STFB)	Near Term Fire Behavior (NTFB)	Fire Spread Probability (FSPro)
Inputs	Canopy characteristics from spatial layers (LCP). Analyst specifies foliar moisture content. Spotting tree species is always grand fir with a DBH of 20 cm (7.9 inches). Analyst sets spotting probability. Wind speed/direction is constant for entire burn period, but can use gridded winds that are modified based on topography. Weather is static, though dead fuel moistures can be conditioned.	Spotting tree species is always grand fir with DBH of 20 cm. Distance and perimeter resolutions are determined from the LCP resolution; timestep is 60 minutes. Wind speed/direction input can be changed hourly. Forecast wind speed and direction are for every 3 hours. Gridded winds are not yet available.	Canopy characteristics are from spatial layers (LCP). Foliar moisture content always 100%. Spotting tree species is always grand fir with a DBH of 20 cm. User sets spotting probability for each fire danger (ERC) bin. Winds can be probabilistic or forecast or combination. Weather can be probabilistic or forecast or combination. Ignition delay is optional.
Spotting Process	Fire behavior is calculated for each cell. Nodes are on fixed grid equal to LCP spatial resolution. For cells predicted to have active or passive crown, 16 incrementally-sized embers are lofted. Max ember distance & azimuth are calculated using canopy cover, crown fraction burned, elevation, and all available wind information. User-set spotting probability determines which predicted crown fire cells (and associated nodes) can produce spots. Those nodes generate a single ember with random distance from zero to the max for that node. Embers landing on unburnable or already burned substrate do not ignite. Embers landing on burnable substrate always ignite (Finney 2002). Similar to spotting in FlamMap 5.0 and FSPro.	Vertices loft 16 incrementally sized embers. The number of vertices depends on perimeter and distance resolutions & timestep. Each ember goes through a random draw process based on user-set spotting probability Ember distances and azimuth are based on canopy cover, crown fraction burned, elevation, winds, and species/DBH. Embers are tracked until they burn out or land. Ignores all embers that land within one cell from where the ember originated, as the main fire would eventually burn over these spot fires. A spotting grid overlaid onto the LCP allows the first spot that lands in a burnable fuel model to "seize" that cell so no other spots can land in that particular cell.	Same process as STFB

(continued on next page)

System	Short Term Fire Behavior (STFB)	Near Term Fire Behavior (NTFB)	Fire Spread Probability (FSPro)
Outputs	Models fire behavior for every cell simultaneously for a single scenario, and uses MTT to calculate fastest fire travel paths. Embers produced only with passive and active crown fire. Randomly lofts a single ember from a node if the predicted fire type is passive or active crown fire.	Simulates lofting and downwind travel of individual embers of different sizes from each vertex that exhibits passive or active crown fire.	Fire probability surface output that may or may not distinguish spot fire activity.
Limitations & Assumptions	Spotting only occurs when passive or active crown fire is modeled. Finney and Scott & Reinhardt methods are available for crown fire; each calculates crown fraction burned (CFB) differently. CFB and canopy cover are used to determine "number of torching trees" (1-10) used in firebrand lofting height. More embers will be lofted at finer landscape resolutions. Faster ROS will encounter more nodes, but the absolute number of nodes is static. One ember per node; less chance than in NTFB/FARSITE that an ember will travel the maximum distance. **NOTE: Users will probably want to set spotting probability higher in STFB than for FARSITE/NTFB tools.**	Grand fir is used as the spotting tree species for the entire landscape. Distance resolution, perimeter resolution, and timestep are automated. The minimum spotting distance (set to the landscape resolution) essentially skips the first 'cell'. For example, on a 60-meter landscape, no spots occur in the first 60 meters from the perimeter, but any viable embers that land beyond 60 meters can produce spot fires. **NOTE: Users will probably want to set spotting probability lower in NTFB than in systems using MTT (STFB, FSPro).**	Same as STFB. Finney and Scott & Reinhardt crown fire methods are available; each calculates crown fraction burned (CFB) differently. CFB and canopy cover are used to determine the number of torching trees used in firebrand lofting height. **NOTE: Users will probably want to set spotting probability higher in FSPro than for FARSITE/NTFB tools. Calibrate FSPro with STFB utilizes consistent spotting methods.**

6.2 Active Crown Fire Behavior

6.2.1 Definitions

Crown Fraction Burned (CFB) is a theoretical concept that is used to model and classify crown fire. It may be observable after the fact in burn severity assessments.

Passive Crown Fire (Intermittent or Persistent Torching) occurs where surface fire intensity is sufficient to ignite tree crowns, individually or in groups, but winds are not sufficient to support propagation from tree to tree. CFB between 0.10 and 0.90.

Active Crown Fire occurs where surface and crown fire energy are linked. Surface intensity is sufficient to ignite tree crowns and fire spread and intensity in the tree crowns encourages surface fire spread and intensity. CFB at least 0.90.

Independent Crown Fire occurs (rarely) where tree crown loading and flammability is sufficient to carry fire without surface fire contribution under ambient weather and wind conditions. CFB generally approaching 1.0

Isolated Tree Torching should not be considered crown fire, though it may be an indicator of potential later in the burn period. It usually occurs due to anomalies in surface fire behavior due to jackpots of surface fuel, isolated terrain features, or brief wind gusts. CFB is less than 0.10

6.2.2 Active Crown Fire Rate of Spread and Flame Length

After the 1988 fire season, Rothermel (1991) developed an empirical model for estimating crown fire spread rates and fireline intensities, referencing several fires from the Rocky Mountains in its development. Based on fire behavior in Fuel Model 10, the calculation is essentially:

$$ROS_{ActiveCrownFire} = 3.34 *_{ROSFuelModel10};$$

$$(Assuming\ MFWS = 20ft\ windspeed * 0.4)$$

Anderson (1982), when describing the original 13 fuel models, identified several of them as representative of crown fire behavior in several classic types:

- Fuel Model 4 (Chaparral) for New Jersey Pine Barrens and Lake States Jack Pine
- Fuel Model 6 (Dormant Brush) for Alaska Spruce Taiga
- Fuel Model 7 (Southern Rough) for Alaska Black Spruce/Shrub Communities

Bishop (2010), in developing the Fireline Assessment Method (FLAME), averaged spread rates for fuel models 5, 6, and 7 to estimate crown fire spread.

Fuel Models sh5 (145) and sh7 (147) have been used in the same manner in spatial modeling in different situations.

Caution: Using surface fuel models to represent crown fire behavior may not accurately provide for the calculation of Crown Fraction Burned (CFB) or the modeling of increasing spread due to passive crown fire (torching and spotting) behavior in spatial fire analyses. It may also over-estimate fire spread and intensity under moderated environmental conditions.

6.3 Crown Fire Initiation and Propagation

In the publication *"Conditions for the start and spread of crown fire"*, C.E. Van Wagner (1977) identified that crown fire is the interaction between separate fuel layers in forested areas.

Further, he described two processes and defined models for estimating their potential:

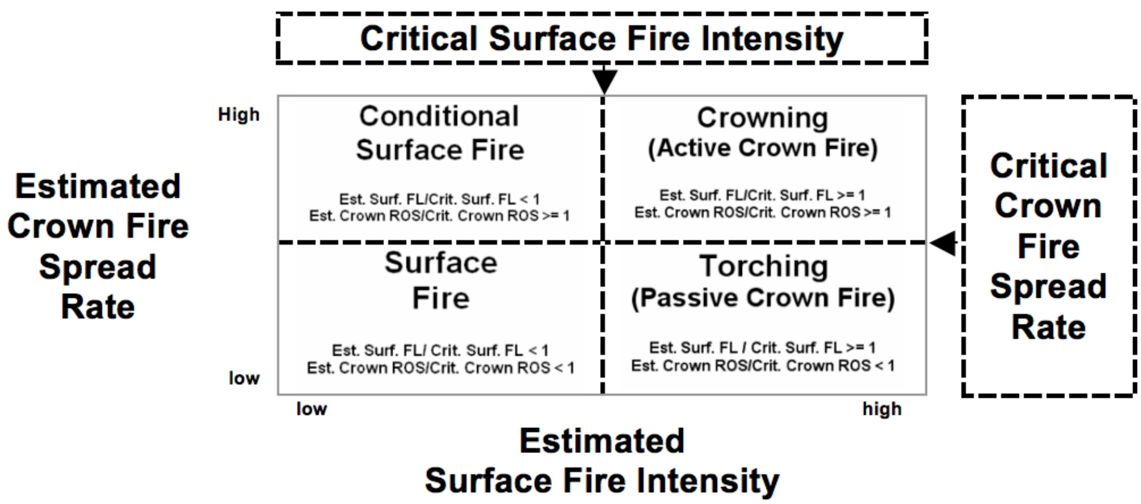
- Crown Fire Initiation is an indicator of the potential for surface fire to ignite tree crown and produce either passive or active crown fire. Inputs include the gap between the surface fuels and the tree crowns (Canopy Base Height – CBH), the foliar moisture content (FMC) of the tree crowns. The result is a threshold surface fire intensity required to produce some crown fire.
- Active Crown Fire Propagation (Crown Spread) is an indicator of the potential for continuous spread through the tree crowns. Inputs include only a characterization of the canopy fuel density in a single number. The result is a threshold rate of spread required to sustain a "solid crown flame…with associated horizontal spread."

These models are very coarse due to the way they represent highly variable characteristics, canopy base height and canopy fuel density. Because they are so variable, their inputs represent grand averages and may require adjustment in modeling efforts.

Linking Surface and Crown Fire Behavior (Scott & Reinhardt, 2001)

As shown in this matrix, the Crown Fire Initiation and Active Crown Fire Propagation models work together to estimate when fires will remain as surface, when they will produce torching, or passive crown fire, behavior in the canopy, and when they will progress to active crown fires.

Use the model results from sections 6.3.1 (threshold surface fire intensity) and 6.3.2 (threshold Crown Fire Spread Rate) to compare against estimates of surface and crown fire spread produced using anticipated environmental factors.



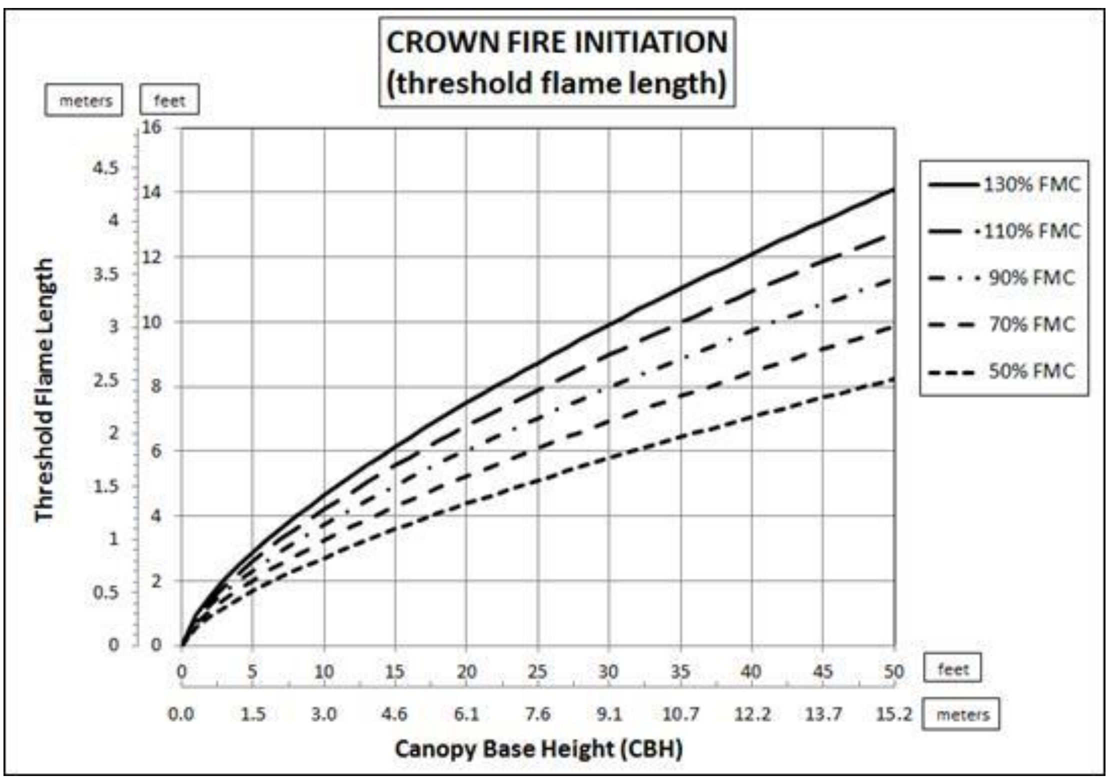
6.3.1 Crown Fire Initiation

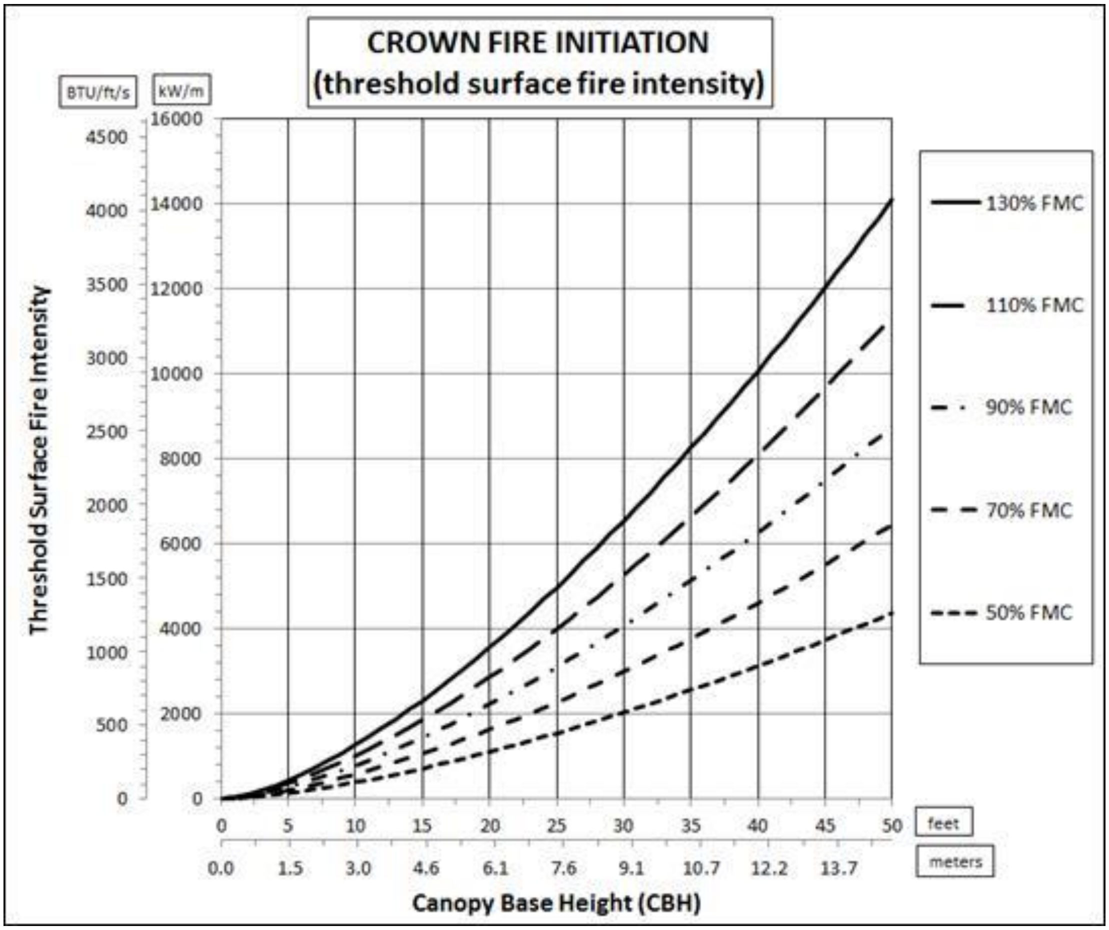
These two graphs identify the height to live crowns (CBH) and the canopy foliar moisture content (FMC) as critical factors, resulting in the threshold surface fire intensity or flame length for evaluating of crown fire initiation. Use either of them to estimate minimum ***surface fireline intensity*** or ***flame length*** that will support at least passive crown fire.

Threshold Evaluation

Use either of the two graphs on the next page. This assessment only determines whether surface fire behavior is sufficient to initiate crown combustion. Both passive and active crown fire are possible if this threshold is met. See the criteria for active crown fire in section 5.5.3.2 to differentiate those conditions.

- Determine the current and/or expected surface intensity (FLI or FL) for that landscape.
- Estimate the CBH and FMC for the landscape you are evaluating for crown fire potential.
- Lookup the threshold surface intensity from either graph here.
- Compare the two intensities. If the projected intensity is greater than the threshold value, crown fire is expected. A ratio of projected over threshold provides a confidence value.




CROWN FIRE INITIATION
(threshold surface fire intensity)
BTU/ft/s
kW/m
Threshold Surface Fire Intensity
4500
4000
3500
3000
2500
2000
1500
1000
500
0
16000
14000
12000
10000
8000
6000
4000
2000
0
0
5
10
15
20
25
30
35
40
45
50
feet
0.0
1.5
3.0
4.6
6.1
7.6
9.1
10.7
12.2
13.7
meters
Canopy Base Height (CBH)
130% FMC
110% FMC
90% FMC
70% FMC
50% FMC

6.3.2 Active Crown Fire Propagation & Crowning Index (CI)

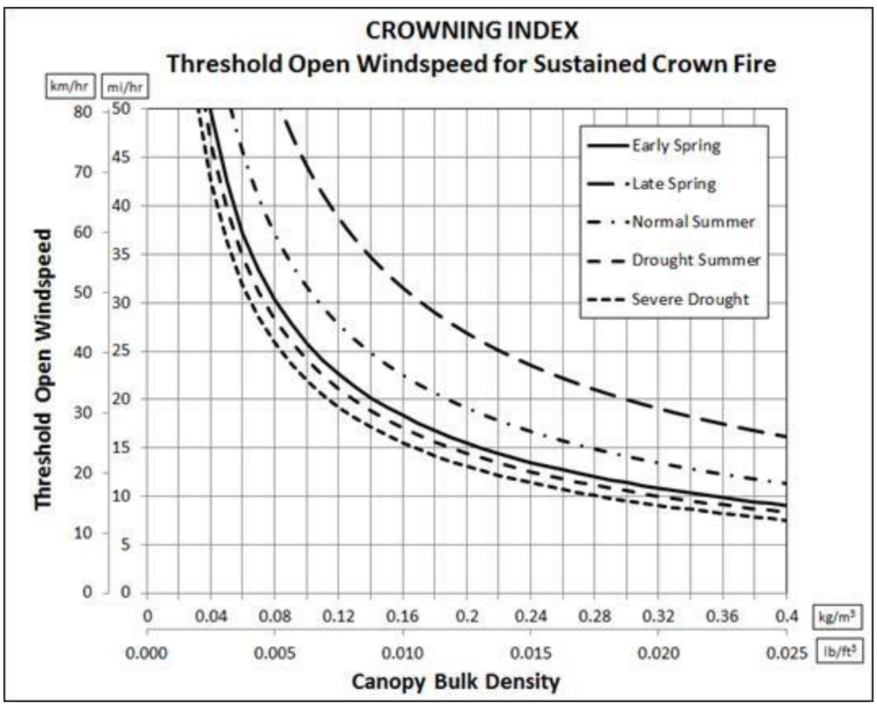
According to Van Wagner (1977), minimum threshold values for canopy fuel/bulk density (CBD) are necessary to sustain active crown fire at given spread rates. And since there is only a single crown fire fuel model, that threshold spread rate can be converted to a threshold windspeed or "crowning index" (CI).

Canopy Bulk Density		Threshold Crown Fire Rate of Spread			
Kg/meter^3	Lb/ft^3	Meters/min	Feet/min	Miles/hr	Chains/hr
0.02	0.0012	150.0	492	5.59	447
0.04	0.0025	75.0	246	2.80	224
0.06	0.0037	50.0	164	1.86	149
0.08	0.0050	37.5	123	1.40	112
0.1	0.0062	30.0	98	1.12	89
0.12	0.0075	25.0	82	0.93	75
0.14	0.0087	21.4	70	0.80	64
0.16	0.0100	18.8	62	0.70	56
0.18	0.0112	16.7	55	0.62	50
0.2	0.0125	15.0	49	0.56	45
0.22	0.0137	13.6	45	0.51	41
0.24	0.0150	12.5	41	0.47	37
0.26	0.0162	11.5	38	0.43	34
0.28	0.0175	10.7	35	0.40	32
0.3	0.0187	10.0	33	0.37	30
0.32	0.0200	9.4	31	0.35	28
0.34	0.0212	8.8	29	0.33	26
0.36	0.0225	8.3	27	0.31	25
0.38	0.0237	7.9	26	0.29	24
0.4	0.0250	7.5	25	0.28	22

Threshold Evaluation

The table and graph to the right provide threshold values for both ROS(active) and open 20 ft windspeed.

For a given CBD, if observed or forecast 20 ft wind or projected ROS(active) are larger than these threshold values, sustained active crown fire is expected. A ratio of estimate/threshold provides a confidence value.



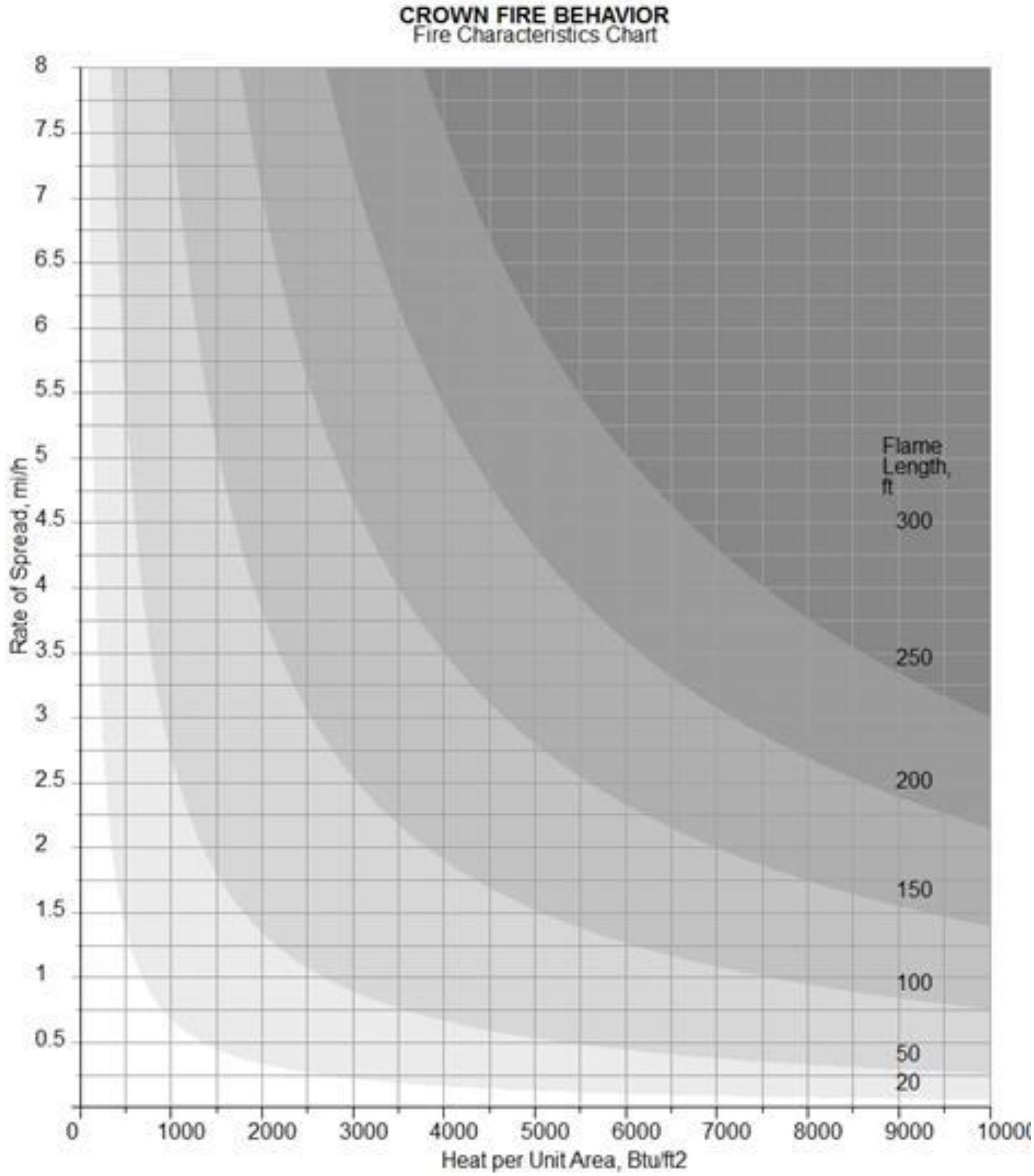
6.3.3 Finney and Scott/Reinhardt Approaches to Crown Fire Behavior

All approaches identify the threshold for predicting crown fire initiation and active crown fire spread using the same criteria, based on the Van Wagner Crown Fire Initiation and Propagation models. They diverge in the way they estimate:

- final spread rates for passive and active crown fire,
- Crown Fraction Burned (CFB)
- Final Fireline Intensity
- Fire Type (Surface, Passive, Active)

	Modeling System		
Model Used	**CFFBP Van Wagner (1977)**	**Surface Fire Control Finney (1998)**	**Crown Fire Control Scott and Reinhardt (2001)**
Surface Fire	Van Wagner (1977) Integrated, empirical model	Rothermel (1972)	Rothermel (1972)
Crown Fire Spread		Rothermel (1991)	Rothermel (1991)
Crown Fire (Torching) Initiation Threshold Spread Rate	Van Wagner (1977)	Van Wagner (1977)	Van Wagner (1977)
Active Crown Fire Propagation Threshold Spread Rate	Van Wagner (1977)	Van Wagner (1977)	Van Wagner (1977)
Methods Applied	**CFFBP Van Wagner (1977)**	**Surface Fire Control Finney (1998)**	**Crown Fire Control Scott and Reinhardt (2001)**
Crown Fraction Burned	Natural Log function based on the difference between estimated spread rate and ***initiation threshold*** spread rate. 90% when estimated spread rate is 10m/min greater than ***Initiation threshold*** spread rate.	Natural log function based on the difference between the estimated ***surface spread*** rate and the ***Initiation threshold*** rate. 0.9% when surface spread rate reaches 90% of difference between ***Initiation threshold*** and ***Active Propagation threshold***.	Proportionally intermediate between 0 (surface fire) and 1.0 (active Crown Fire) based on input windspeed and where it falls between windspeeds at ***Initiation Threshold*** and ***Active Propagation threshold*** spread rates.
Passive Crown Fire Spread	Integrated within basic spread model for conifer & mixedwood fuel types. *Fire type designated as Passive based on estimated **Crown fraction Burned** (see below)*	Surface Fire spread rate plus any spotting spread	Based on Crown Fraction Burned (CFB). Proportionally intermediate between surface spread rate and ***Active Propagation threshold***, based on crown fraction burned plus any spotting spread
Final Spread Rate with Active Crown Fire	Integrated within basic spread model for conifer & mixedwood fuel types *Fire type designated as Passive based on estimated **Crown fraction Burned** (see below)*	Proportionally intermediate between surface spread rate and Rothermel 1991 Model based on Crown Fraction Burned. *Generally, less than half of Rothermel model rate*	Spread Rate estimated directly from Rothermel 1991 crown fire spread model
Fire Intensity	Byram (1959)	Byram (1959) for Surface Thomas (1963) for Crown	Byram (1959) for Surface Thomas (1963) for Crown
Fire Type: Surface Passive Active	Based on ***Crown Fraction Burned*** <0.1 = surface 0.1 to <0.9 = passive 0.9 to 1.0 = active	Based on Crown Fire ***Initiation*** and ***Propagation*** thresholds (see above) Surface if ROS < Init. Criteria Active if ROS > Active Crit. Passive Between	Based on Crown Fire ***Initiation*** and ***Propagation*** thresholds (see above) Surface if ROS < Init. Criteria Active if ROS > Active Crit. Passive Between

6.4 Interpreting Expected Crown Fire Behavior Estimates



6.5 Crown Fire Size and Shape

6.5.1 Crown Fire, Area Estimation for Point Source Fires, in Acres

Spread Distance, in Miles	Maximum Sustained 20 ft Windspeed, in mph — Area, in Acres									
	10	15	20	25	30	35	40	45	50	60
0.25	14	11	9	8	7	6	5	5	4	4
0.5	56	44	36	30	26	23	21	19	17	15
1	223	175	144	122	106	94	84	76	69	59
1.5	503	393	323	274	238	210	188	171	156	133
2	894	699	574	487	423	374	335	303	277	237
2.5	1396	1093	898	762	661	584	524	474	433	370
3	2011	1574	1293	1097	952	842	754	683	624	532
3.5	2737	2142	1759	1493	1296	1146	1026	929	849	724
4	3574	2797	2298	1950	1693	1496	1340	1214	1109	946
4.5	4524	3540	2908	2468	2143	1894	1696	1536	1404	1198
5	5585	4371	3590	3046	2646	2338	2094	1897	1733	1478
5.5	6758	5289	4344	3686	3201	2829	2534	2295	2097	1789
6	8042	6294	5170	4387	3810	3367	3016	2731	2496	2129
8	14298	11190	9191	7799	6773	5985	5362	4856	4437	3785
10	22340	17484	14362	12186	10582	9352	8378	7587	6933	5914
12	32170	25176	20681	17547	15238	13466	12064	10926	9984	8516
14	43787	34268	28149	23884	20741	18329	16420	14871	13589	11591
16	57191	44758	36766	31195	27090	23940	21447	19423	17749	15139
18	72382	56647	46531	39481	34286	30300	27143	24583	22463	19160
20	89361	69935	57446	48742	42329	37407	33510	30349	27733	23654
22	108127	84621	69510	58978	51218	45262	40547	36722	33557	28622
24	128680	100706	82723	70189	60954	53866	48255	43703	39935	34062
30	201062	157353	129254	109670	95240	84165	75398	68285	62399	53222
35	273668	214175	175929	149273	129632	114559	102625	92944	84931	72441
40	357443	279738	229785	194969	169315	149627	134041	121396	110931	94617

6.5.2 Crown Fire, Perimeter Estimation for Point Source Fires, in Miles

Spread Distance, in Miles	Maximum Sustained 20 ft Windspeed, in mph — Perimeter, In Miles									
	10	15	20	25	30	35	40	45	50	60
0.25	1	1	1	0	0	0	0	0	0	0
0.5	1	1	1	1	1	1	1	1	1	1
1	2	2	2	2	2	2	2	2	2	2
1.5	3	3	3	3	3	3	3	3	3	3
2	5	4	4	4	4	4	4	4	4	4
2.5	6	5	5	5	5	5	5	5	4	4
3	7	6	6	6	6	6	5	5	5	5
3.5	8	7	7	7	7	7	6	6	6	6
4	9	8	8	8	8	7	7	7	7	7
4.5	10	10	9	9	9	8	8	8	8	8
5	11	11	10	10	10	9	9	9	9	9
5.5	12	12	11	11	10	10	10	10	10	10
6	14	13	12	12	11	11	11	11	11	11
8	18	17	16	16	15	15	15	14	14	14
10	23	21	20	20	19	19	18	18	18	18
12	27	25	24	23	23	22	22	22	21	21
14	32	30	28	27	27	26	26	25	25	25
16	36	34	32	31	30	30	29	29	29	28
18	41	38	36	35	34	34	33	33	32	32
20	45	42	40	39	38	37	37	36	36	35
22	50	47	44	43	42	41	40	40	39	39
24	54	51	48	47	46	45	44	43	43	42
30	68	64	61	59	57	56	55	54	54	53
35	79	74	71	68	67	65	64	63	63	61
40	91	85	81	78	76	75	73	72	71	70

6.5.3 Crown Fire Length to Width Ratio

20ft Windspeed (mph)	Length to Width (x:1)
10	2.2
15	2.9
20	3.5
25	4.1
30	4.8
35	5.4

20ft Windspeed (mph)	Length to Width (x:1)
40	6
45	6.6
50	7.3
55	7.9
60	8.5
65	9.1

6.6 References

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7. Fire Behavior Assessment

7.1 A Process to Follow

Examine current fire situation (location, factors, spread direction & fire behavior)

- Fuel: Is it burning in grass, litter, or into shrubs and crowns?
- Fuel Moisture: are fuels dry? Are they still green?
- Terrain: Is it burning upslope, downslope?
- Weather: Is the wind pushing it, is it sheltered from the wind?
- Fire Behavior: is it smoldering, creeping, or actively spreading? Are the flames low, or is it burning hot?

Evaluate the unburned areas where you are and will be working

- Which spread directions do you expect to be active?
- Which seems like the spread directions that will produce the most problems?
- Which of the spread directions are of most concern to you?

Anticipate the expected fire situation in those areas

- Fuel: What fuel is it going to move into in that direction? Will it burn hotter and faster? Slower & cooler?
- Fuel Moisture – will the change in fuel moisture encourage extreme fire behavior?
- Terrain – slope reversal? Flat to upslope? Will changes increase or lower fire behavior?
- Weather - As the fire moves, will it be more exposed to the wind? Will the wind increase in the future?
- Fire Behavior - do you anticipate the fire behavior, based on your anticipated changes being manageable?

Assess Fire Risk: Interpret Ignition and Crown Fire Potential

- Is it the typical dry period for the area?
- Is the overall drought situation enough to make it worse?
- Has there been recent crown fire on this or other fires in the area?
- Is the humidity, and fine fuel moisture, low enough to encourage intense surface fire?
- Is backing fire causing torching? If so, expect crown fire with head fire.
- Is fire moving up ladder fuels? Expect at least short crown fire runs.

Project Fire Spread, Flame Length and Spotting Distance

- Select proper tool for assessment. FLAME, Surface Fire Behavior Lookup Tables and Nomographs, Spotting Nomograms, and crown fire assessment tools are included here.
- Can you calibrate projections with current fire behavior?
- How precise do the projections need to be?

Determine Decision Thresholds to Insure LCES

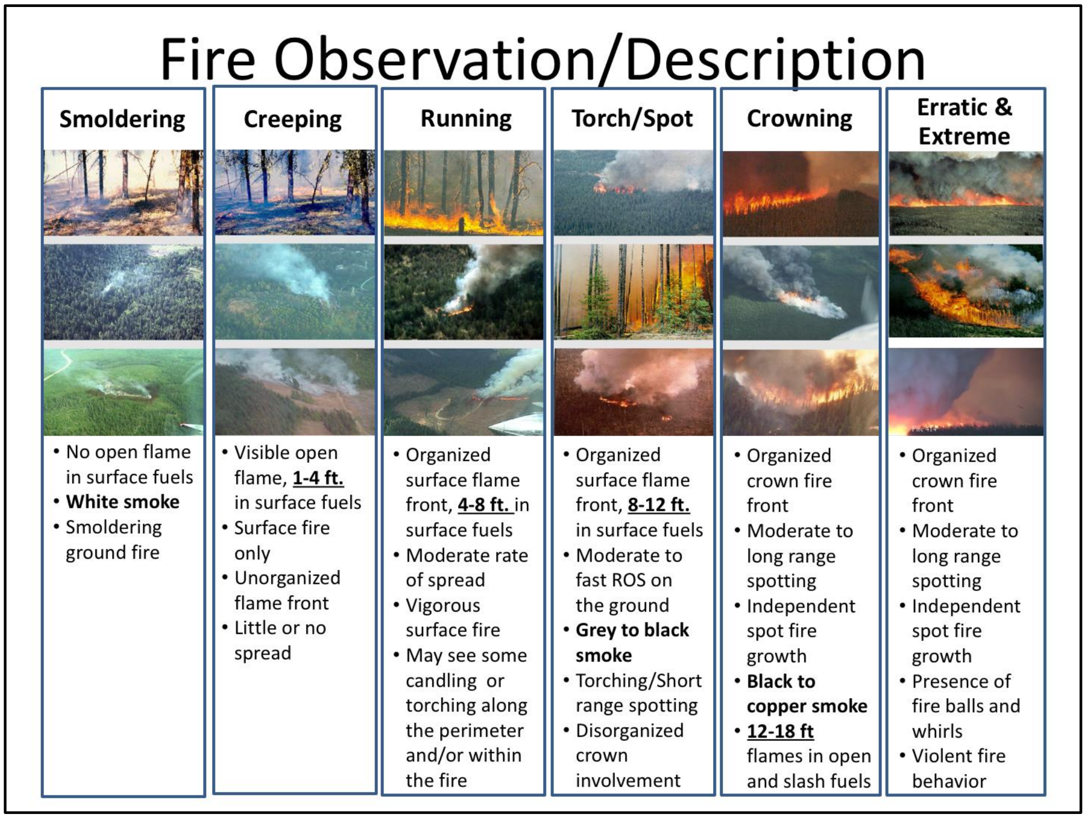
- Determine time frames for escape to safety & escape routes make sense. What windspeeds or changes in fire behavior will render those time frames insufficient?
- Identify best locations and methods for lookout to monitor and validate your assessment
- Insure that weather & fire behavior observations are communicated to the entire crew.
- Will Fatigue and Logistics factors impact these decisions?

Document Your Assessment

- Record your observations and assumptions
- Use worksheets and include notes for each assessment
- Include assessments and decisions in personal logs
- Remember: “If you’re not keeping score, it’s just practice”

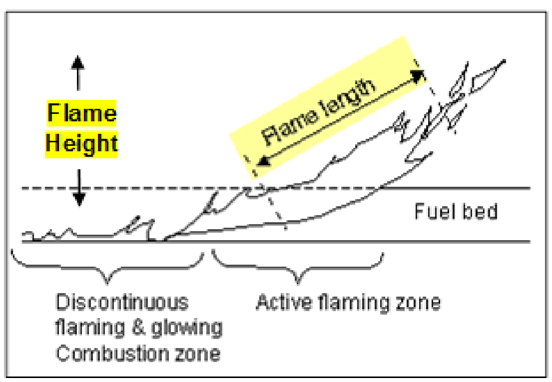
7.2 Observing Current Fire Behavior

7.2.1 Visual Fire Behavior Descriptions



7.2.2 Observing Flame Length vs. Flame Height

Observing Flames, as proxy for fireline intensity and indicator of tactical limitations, requires careful observation of flame length vs flame height. It is also important to identify whether the observation is for head, flank, or back of the fire.



Flame Length: The distance measured from the average flame tip to the middle of the active flaming zone at the base of the fire. It is measured on a slant when the flames are tilted due to effects of wind and slope.

Flame Height: The average height of flames as measured vertically, up and down. It is estimated by comparing the flame to a nearby object of known height. Flame height is needed to estimate spot distance from a burning pile.

7.2.3 Rate of Spread Estimator

From the Interagency Wildland Fire Module Field Guide

Spread Distance (ft)				
1	3	5	10	ROS ch/hr (ft/min)
Time in Minutes (') and seconds (")				
3'38"	10'55"	18'10"	36'22"	¼ (¼)
1'49"	5'27"	9'05"	18'10"	½ (½)
55"	2'44"	4'33"	9'05"	1 (1)
36"	1'49"	3'02"	6'04"	1.5 (1-2)
27"	1'22"	2'16"	4'33"	2 (2)
18"	55"	1'31"	3'02"	3 (3)
14"	41"	1'08"	2'16"	4 (4-5 ft)
11"	33"	55"	1'49"	5 (5-6)
9"	27"	45"	1'31"	6 (6-7)
8"	23"	39"	1'18"	7 (7-8)
7"	20"	34"	1'08"	8 (9)
6"	18"	30"	1'01"	9 (10)
5"	16"	27"	55"	10 (11)
4"	11"	18"	36"	15 (16-17)
3"	8"	14"	27"	20 (22)
2"	7"	11"	22"	25 (27-28)
2"	5"	9"	18"	30 (33)
2"	5"	8"	16"	35 (38-39)
1"	4"	7"	14"	40 (44)
1"	3"	5"	11"	50 (55)
Spread Distance (ft)				

Use this chart to help estimate rate of spread

Here's how:

1. Measure out 1, 3, 5 or 10 feet. Mark distance with two points.
2. Time fire as it spreads between your two points and record this time.
3. Using the appropriate spread distance column (1, 3, 5 or 10), place your time on the sheet between two times listed, your "bracketed" times.
4. Move to the right with the bracket times. This is your ROS range.

Time Key
1' 49" = 1 minute and 49 seconds
36" = 36 seconds

Example: Say you're monitoring a backing fire burning in light ponderosa needle cast. You measure out 3 feet, and place two stones at each of the points. You time the fire as it moves between the stones. In this case, say the fire takes 1 minute 6 seconds (1'6") to move 3 feet. Looking at the 3 column, you move down until you see two times which bracket our time: 1'22" and 55". You then scroll right and see that the rate of spread is between 2 and 3 chains per hour.

7.2.4 Fire Behavior Observation Reports

Fire Name:____ Fire #____________

Management Unit:________________________________Date:__________Time:_____

Current Fire Size:__________Observation Location (map grid/elev.etc.):____________________

Attach current map indicating active fire perimeter, spread direction and other significant information.

Fuel Model/Vegetation Type (of active area):____________________________________

Fire Activity: Creeping, Running, Torching, or Crowning. ________________________________

- Rate of Spread_________ch/h Type of spread Head Flanking Backing Average (select any that apply)
- Perimeter growth__________chains, direction________Growth Rate (chains/time)_____________
- Percent of perimeter actively burning?________.Location(s)____________________________
- Max temp/time_____Min temp/time_____ Min RH/time_____ Max RH/time
- Wind: Max sustained dir/time____
- Smoke: (describe column: color, shape, etc)______________________________________
- Distance to MMA, Trigger Points, other values at risk (note on attached map also)_______________

Other notes (i.e. influencing factors – topography, shading, etc., potential fuel model changes, resistance to control efforts, structures (if applicable), more on observations above.)

Prepared by:____Date____________
Name, Module, and Qualification

Reviewed by:____Date____________
Name, Module, and Qualification

Attached Products: (check)

- ☐ **FIRE BEHAVIOR OBSERVATIONS**
- ☐ **SMOKE OBSERVATIONS**
- ☐ **SPOT WEATHER FORECAST REQUEST**
- ☐ **FIRE PERIMETER/ AREA MAP**
- ☐ **FIRE WEATHER OBSERVATIONS**
- ☐ **FUEL MOISTURE SAMPLING SHEET**
- ☐ **ICS 214 UNIT LOG**
- ☐ **PHOTO LOG**

7.3 Evaluating Expected Fire Behavior

7.3.1 Selecting the Best Tool

The fire spread and intensity models have been configured in a variety of forms to address fire potential in different temporal and spatial configurations. This table can help focus the assessment with the most helpful information.

How will the tool help answer your question?	**How will fire behavior change with the next big change in fire environment?** **Sensitivity Analysis**	**Where will fire go today and how long will it take?** **How will fire behavior vary across areas of interest during the burn period?**	**Where will fire go over several days given changing weather as well as fuel and terrain?**	**What risk do identified values face over a given planning period?**
Tool or Model	BehavePlus Lookup Tables Nomograms Nomographs Nexus FLAME/CPS	Short-Term Fire Behavior (STFB) or FLAMMAP Minimum Travel Time (MTT) (Finney 2002)	Near-Term Fire Behavior (NTFB) or FARSITE (Finney 1998)	Fire Spread Probability (FSPro) Uses Minimum Travel Time (MTT) (Finney 2002)
Best Use, Calc Time	Fireline	Incident/Event 15 min to 1 hour	Incident Planning 1 to 3 hours	Risk Assessment 2 or more hours
Forecast Horizon	Single Period	Up to 3 days if weather persistent	Up to 6 days (evaluate forecast confidence)	One week to 30 days
Weather	Single weather (wind & fuel moisture) scenario	Single weather (wind & fuel moisture) scenario over duration of run	Hourly, variable weather (wind & fuel moisture) over duration of run	Short term forecast plus ERC seasonal trend after that produce range of daily weather scenarios
Gridded Wind	No	Yes (WindNinja)	No	No
Spotting	Yes Max Spot Distance, Probability of Ignition	Yes Spotting Distance & Frequency (1 ember per node; spotting probability value higher than NTFB; start with .10% spotting probability)	Yes Spotting Distance & Frequency (16 embers per vertex; spotting probability value lower than STFB; start with .05%)	Yes (like STFB)
Principal Output(s)	***Not Spatial*** Rate of Spread Flame Length	***Spatial*** Major flow paths and arrival times Perimeters Fire behavior grids	***Spatial*** progression perimeters	***Spatial*** probability contours

7.3.2 Basic Fire Behavior Tools

Manual (Fireline) Methods:

Lookup tables, Nomograms, and Nomographs are all direct implementations of the surface fire spread and spotting models and are constructed for use without computers.

1. *Lookup Tables and Fire Behavior Nomograms* are constructed for only the original 13 fuel models and represent only surface fire behavior. They provide simple means to estimate fire behavior on the fireline based on observed fine fuel moisture, fuel model, wind and slope. They can be found in Section 5 (Surface Fire Behavior)
2. *Spotting Nomograms* are for single torching trees only and do not account for terrain features. They can be found in Section 6 (Crown Fire Behavior)
3. *Fire Behavior Nomographs* (Scott, 20??) include both the 13 original fuel models and each of the additional 40 models implemented more recently (Scott and Burgan, 2001)

FLAME and the Campbell Prediction System are systems rooted in the concept that in the fire response to a fire, firefighters need to have a thought process that can help them identify what the fire is doing, how that relates to the fire environment (wind, slope, fire flammability), and what the upcoming changes will produce. Further they focus on firefighter safety implications and encourage means of organizing thoughts for briefing firefighters.

While neither is in widespread use, they represent important attempts to blend the fire behavior prediction models and processes with fireline operations.

The Fireline Assessment Method, FLAME (Bishop, 2007) expects users to:

1. describe current fuels, winds, and terrain influences and the fire spread it is currently producing
2. to identify what the "Next Big Change" will be during the burn period (slope reversal, fuel type change, forecasted change in the wind)
3. Apply multipliers for windspeed, fuel, and slope to produce new estimates of fire spread to apply tactically.

Campbell Prediction System(CPS) (*http://www.emxsys.com/cps/*)

CPS identifies "three primary forces causing variations in fire behavior: wind slope and pre-heat." It highlights the need to:

1. evaluate the specific *"alignment of [these] forces"* on each side of a fire and place on the landscape and recognize the *"fire signature, [or] the observed fire behavior"* it produces.
2. Identify *"trigger points where a change in the alignment of forces will change the fire behavior [signature], creating either opportunity or danger."*

BehavePlus

A desktop computer application that is composed of a collection of mathematical models that describe fire behavior, fire effects, and the fire environment based on specified fuel and moisture conditions. The program simulates rate of fire spread, spotting distance, scorch height, tree mortality, fuel moisture, wind adjustment factor, and many other fire behaviors and effects; it is commonly used to predict fire behavior in multiple situations.

- *Online Reference and Learning Resources*

  Due to periodic updating, users should check the "Splash" information found in the help menu to determine the version currently installed. Install the latest version. The latest version can be identified and downloaded, if necessary at https://www.frames.gov/partner-sites/behaveplus/home/ .

  A collection of publications that support the BehavePlus, modeling system https://www.frames.gov/partner-sites/behaveplus/publications/

  A comprehensive set of training resources can be found at https://www.frames.gov/partner-sites/behaveplus/tips-training/

  An online self-paced course can be found among the self-study courses at https://www.frames.gov/onlinecourses/course/index.php?categoryid=11

- *Creating a Workspace*

  To take full advantage of the BehavePlus system, users should consider recording their inputs, assumptions, and configurations within the BehavePlus file structure rather than on paper worksheets provided in the past. There are now enough options within the system that only knowing the fire environment inputs may not be sufficient to duplicate the results. Use these few guidelines to establish a BehavePlus Workspace and record all work, including documentation, by saving in the appropriate file format provided in the software.

  In the BehavePlus "File" menu, the workspace submenu allows the user to open an existing workspace, create a new empty workspace, or clone the currently open workspace to a new location. The default workspace is located with the program files and is opened by default each time BehavePlus is opened.

  Users should consider either creating a workspace on external storage (network folder or usb flash drive) or cloning the default workspace to one of those locations at the end of a work session when data files need to be shared, backed up, or archived.

  There are individual folders for ***worksheet*** files, ***fuel model*** definition files, ***fuel moisture scenario*** files, individual ***run*** files that include system settings and modeling inputs, and ***unit settings***. Work should be stored there.

- *Models and Tools Specific to BehavePlus*
  - ✓ Two-Fuel Model Projection
  - ✓ Special Case Fuel Models (Palmetto-Gallberry and Western Aspen)
  - ✓ The Tools Menu includes Units Converter, Relative Humidity estimator, Fine Dead Fuel Moisture (Fosberg) Estimator, Slope from Map Inputs estimator, and Sun-Moon Calendar

NEXUS

NEXUS 2.1 is crown fire hazard analysis software that links separate models of surface and crown fire behavior to compute indices of relative crown fire potential. Use NEXUS to compare crown fire potential for different stands, and to compare the effects of alternative fuel treatments on crown fire potential. NEXUS includes several visual tools useful in understanding how surface and crown fire models interact.

It is available from http://www.fire.org

Mobile Apps (pending)

7.3.3 Spatial Analysis Tools

FARSITE (https://www.firelab.org/project/farsite)

FlamMap (https://www.firelab.org/project/flammap)

7.3.4 Online Resources

***Wildland Fire Decision Support System (WFDSS)* –**
https://wfdss.usgs.gov

- WFDSS Help - http://wfdss.usgs.gov/wfdss/WFDSS_Contactus.shtml
- WFDSS Training Resources - http://wfdss.usgs.gov/wfdss/WFDSS_Training.shtml

Interagency Fuels Treatment Decision Support System (IFTDSS)
https://iftdss.firenet.gov/

Alaska Fire Weather & Fire Behavior Prediction Tool - https://akff.mesowest.org/tools/fbp/

Great Lakes Fire Weather & Fire Behavior Prediction Tool

https://glff.mesowest.org/tools/fbp/

7.4 Verification, Calibration, and Validation

7.4.1 Reference Fire History

Wildland Fire Library (https://firelibrary.org)

The Wildland Fire Library is a collection of long-term assessments, fire progressions, fire behavior reports, and other documents and resources to support fire modeling and assessment of long-duration fires. Each file is tied to some **event** with a location, a start date, and background information.

Event **locations**, **file attachments**, and **remarks** are optional, but because events can represent many things, every event needs one **tag** to indicate document type:

Progression Fire Progressions	FireDanger Fire Danger & PocketCards
WindWizard WindWizard Library (KMLs)	Report Reports, Reviews, & Case Studies
FireWeather Critical Fire Weather	Burnover Fatalities or Entrapments (Burnovers)
LTA Long-term Assessments	Note Fire Modeling & LCP Calibration Notes
SeasonEnd Season-ending Analyses	
SPP Structure Protection Plans	

The **main map** shows all events by tag-derived category. You can also **browse the full list** and, if something is missing, **login to add your own document.**

This site is operated by Rick Stratton and Jim Edmonds at USFS Pacific NW and Alaska Regions and BLM OR/WA State Office.

"**Those who cannot remember the past are condemned to repeat it.**" George Santayana, 1905

7.4.2 General Analysis Factors

Burn Period

The NWCG Fire Glossary defines the ***burn period*** as that part of each 24-hour period when fires spread most rapidly; typically, from 1000 to sundown.

In most cases, the burn period refers to the period when fire is actively spreading at the head of the fire. If the 6 categories of visual fire behavior are considered, the 24-hour day includes all of them. Field Observers should be careful to report/describe their estimate of burn period accurately and purposefully:

- ***Smoldering*** fire behavior continues around the clock for most active fires. It does not represent any part of an active burn period if reported at the head.
- ***Creeping*** fire behavior may continue through the night, but is generally transitional between smoldering and running fire behavior. Generally, it produces little overall fire spread and is not considered part of the burn period if observed at the head of the fire.
- ***Running*** fire behavior describes what is encountered during the burn period on most days when fire spread and overall growth is low to moderate. However, it may represent transitional fire behavior when more significant Torching/Spotting or Crowning fire behavior occurs during peak hours.
- On days when ***Torching/Spotting*** and ***Crowning*** fire behavior is observed, the burn period should probably exclude much of the time the fire behavior is Running at the beginning and the end of the most active period.

Burn period can vary from day to day for a variety of reasons:

- ***Solar Radiation*** heats fuels as well as warming the air and lowering relative humidity. These influences lower fuel moisture, creating conditions favorable for active burning. Affected by the sun angle based on the time of year and latitude. Cloud cover and canopy shading can further reduce solar radiation.
- ***Fuelbed characteristics*** can influence burn period as well. Moisture content of light fuels, such as grasses, respond more quickly to changes in temperature and humidity.
- ***Diurnal fuel moisture trends*** are affected by the quality of night time humidity recovery and inversions. Slope/aspect and recent precipitation all affect the length of the burning period for a given situation.
- ***Drought*** can influence the length of the burn period through the heat produced in the burning of heavy fuels.
- ***Direction of Spread*** can be an important factor as well. Backing spread can start later and end earlier in the day for a given situation.

In the validation of your estimate, there are tools and criteria that can help identify when the burn period starts and ends.

- ***Fireline Observations*** are probably the first and most important source of information for determining the burn period. Try and get answers to specific questions as you pursue a reasonable estimate. When and where did fire begin to move and when did it slow down on previous days? Was there spread during the night? What were observed spread rates and when?

Sometimes these reports are incomplete and need to be correlated to other information as suggested below. FSPro seeks burn period information for different types of days. These factors suggest that fireline observations should be reinforced with these other information sources where possible.

- ***Sunrise-Sunset Tables*** (time of year and latitude) from BehavePlus and solar radiation sensors can show periodicity and suggest timing of beginning and end of active spread.
- ***Diurnal Wind, Weather and Fuel Moisture Trends*** can similarly show a periodicity that can suggest timing of active spread. Graphs displaying these trends are readily available at http://mesowest.utah.edu.
- ***Fire Progression Maps*** suggest the overall daily spread around the fire, and with knowledge of weather conditions, fuels, slope and spread direction, can be compared to modeled growth. A new resource called the ***Wildland Fire Library***, http://firelibrary.org, provides a variety of historical references including fire progression maps

WFDSS Help suggests that “The default burn period in NTFB is 24 hours; however, modeling a fire overnight is generally not advised. NTFB, like FARSITE, has a tendency to over-predict overnight fire spread. For this reason, most analysts shorten the duration that the modeled fire is allowed to burn each day.”

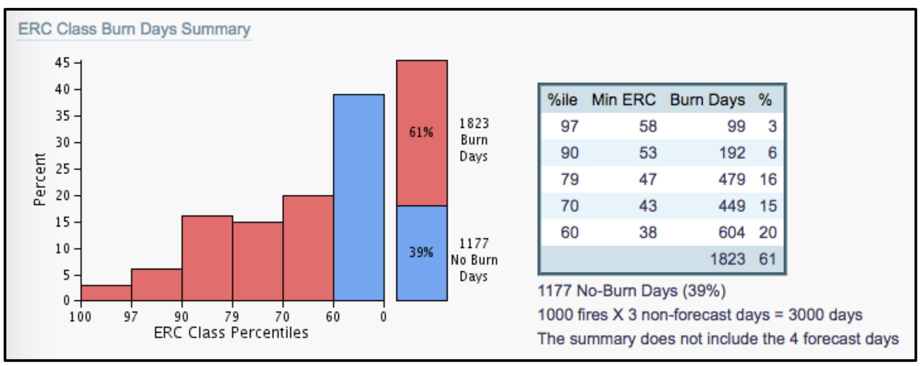
Each fire growth projection, whether using non-spatial tools (BehavePlus) or spatial tools (WFDSS analyses NTFB and FSPro) specify a duration as the number of hours or minutes to obtain a resulting fire size and/or perimeter. Characterizing the duration as the number of hours or minutes in a day (burn period) for a projection allows the user to model growth for multiple days.

Burning Thresholds

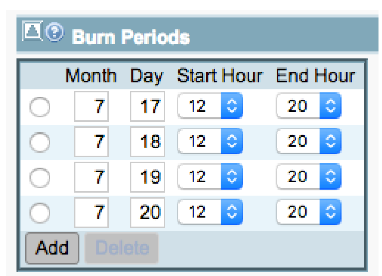
Most of the area burned across any management unit, geographic area, or ecological region occur on relatively few days over the life of the fires that are included in them. ***Burn Day*** can help identify which days have conditions receptive to significant fire spread.

The concept recognizes that there are thresholds in environmental conditions below which significant spread is substantially limited, even when fire spread models estimate that spread will continue. *A simple classification of days into [Burn Days] and 'non [Burn Days]' can greatly improve estimates of area burned.* (Podur and Wotton, 2011). There is important within & between season variation.

1. WFDSS FSPro analysis defines a threshold ERC for each analysis, below which no fire spread is modeled for the entire day. Among its outputs, a distribution of "burn days" spread across the ERC classes is provided. It is possible to define daily environmental conditions favorable to significant growth and use those to estimate the frequency with which they occur to adjust the default 60th percentile ERC as that threshold (Ziel, 2015).



2. WFDSS NTFB analysis requires input of a burn period for each of the included days. Specifying same start and end hour for a given day essentially defines it as a non-burn day. The same daily conditions mentioned for FSPro can be used as criteria to exclude specific days in NTFB analyses.



The Weather Forecast

In most cases, the forecast has difficulty outperforming climatology beyond 48-72 hours. Most important are confidence in wind and precipitation elements. Read the area forecast discussion for insight into the confidence horizon.

Extend STFB and NTFB analyses only to the limits of very high confidence, usually 1-3 days. FSPro Analyses combine forecast and climatology. Extend forecast out beyond 3 days only if confidence for the extended forecast is unusually high. Critically examine the wind speed and direction in the forecast.

Winds

With a sparse network of RAWS stations that provide hourly reports, it may be difficult to find a weather station that represents both windspeeds and directions appropriately for the analysis. Review observations and forecasts carefully for both speeds and direction. Try analyses with alternatives being considered.

Weather Station climatology in FSPro analysis is generally restricted to RAWS installations. For that reason, many analysts choose a combination of 10-minute average and gust windspeeds in those climatological distributions. This results in approximately a 50% increase in windspeeds. ASOS/AWOS climatologies often reflect this higher windspeed. Wind roses for ASOS/AWOS stations are at http://mesonet.agron.iastate.edu/sites/locate.php. This difference is often found in NDFD forecast windspeeds as well. Consider a similar adjustment to 10-min RAWS winds when conducting calibration analyses in STFB and NTFB.

Live Fuel Moistures

7.4.3 Evaluating and Adjusting your Analysis

Verification: *a demonstration that the modeling formalism is correct.*

Though much of the verification work was completed in the development of a model, end users have a responsibility to evaluate Large Scale factors to ensure that the range of variability used produces the range in results that generally fit observed outcomes. Default analysis inputs provide a first step

Calibration: *the estimation and adjustment of the model parameters and constants to improve the agreement between model output and a data set*

Calibration Factors to Consider:

Variability	Large Scale	Medium Scale	Small Scale
Diurnal Changes	*Windspeed & Wind Direction,* *Cloud Cover & Smoke* *Precipitation* *1-hr (when over 24 hours in primarily grass landscapes)*	*1-hr (when over 24 hours in mixed forest, shrub and grass landscapes)*	*1-hr (if burn period only includes peak hours)*
Day-to-Day Variability	*Burn Period length,* *Burn Day frequency*	*1-hr fuel moisture*	*10-hr, 100-hr fuel moistures*
Seasonal Trends	*Burn Period Length,* *Burn Day frequency,* *Herb. Fuel Moisture*	*Woody Fuel Moisture*	
Analysis Constants	*Canopy Cover* *Fuel Model* *Crown Fire Method* *Spotting Frequency*	*Canopy Base Height* *Canopy Bulk Density* *Stand Height*	

Calibration Steps to employ:

- Consider edits to Large Scale Constants first.

  Fuel Model & canopy layers can require local edits due to disturbance, classification errors, and possibly seasonal trends. These fuel characteristics can have a large impact on outputs. It is CRITICAL to account for things that will check or stop fire spread, so ensure that recent historical fires are reflected in the LCP. Also, make sure that rock and water are adequately mapped. But other fuel layer adjustments should be considered only when the changes you contemplate are appropriate and will result in significant changes in fire growth. Otherwise, edits may mask necessary variability.

  Crown fire method and ***Spotting Frequency*** are frequently settings applied consistently with experience in particular landscapes. As these become standard, they become "verified."

- Consider edits to medium and large scale Day-to-Day and Seasonal factors.

  Burn period length and ***burning threshold*** edits should be consistently applied according to seasonally changing day length and according to daily variability when limiting burn period.

  Herbaceous and woody fuel moisture trends should reflect reasonable ranges for season and drought.

- Edits to diurnal weather-related inputs (***temp, rh, windspeed/dir, cloud cover***) should be limited to standard kinds of adjustments to preserve relevance of observed calibrations to forecast projections.

  Windspeed and direction is most important factor. Ensure that “observed” weather reflects observed fire spread and that winds observations are appropriate for situation. ***Precipitation*** estimate may not represent fireline amounts. Consider adjustments carefully.

- Calibration may require a couple iterations.

  Do not over-calibrate to overfit the result.

<u>Validation:</u> *a demonstration that a model, within its domain of applicability, possesses a satisfactory range of accuracy consistent with the intended application of the model.*

Validation is used to evaluate forecast projections from applied calibration adjustments. Keep in mind that forecast errors have large impact on calibrations.

7.5 Documenting your Assessment

7.5.1 Analysis Notes

Identify and explain the key inputs and assumptions that frame the analysis, highlight the primary conclusions, and describe the limitations and uncertainty that limit your confidence in the information provided.

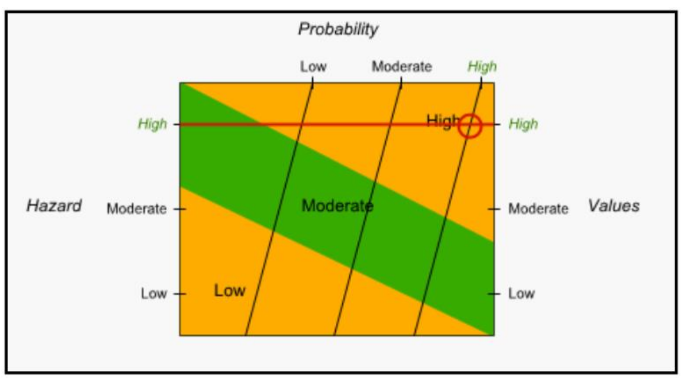
WFDSS analyses allow the analyst to associate Notes sections with every input section of the analysis and in support of the final disposition (accept/reject). But even informal briefings should document the basic assumptions, the expected fire behavior, and the implication for management decisions.

7.5.2 Risk Assessments and Management Decisions

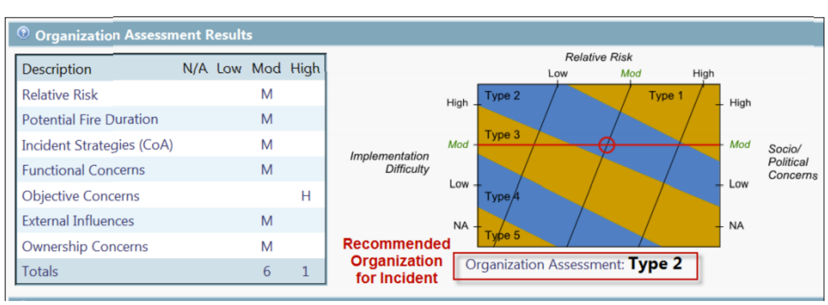
The primary reason for conducting fire behavior assessments is to support decisions. Decisions occur in an environment of uncertainty, and involves choosing a level of risk to avoid, to mitigate, and to accept. All Incidents in WFDSS provide for maintaining an updated Relative Risk Assessment and a dependent Organization Assessment. Both are shown here.

Relative Risk Assessments, in WFDSS, include three primary considerations:

- A Probability Assessment from Time of Season, the barriers to fire spread, and current/expected seasonal severity.
- A Hazard Analysis from fuel condition, current fire behavior, and potential fire growth
- An assessment of Values at Risk based on fires proximity and threat values, identification of cultural and natural values, and Social/Economic concerns



Organization Assessments include the relative risk assessment, an evaluation of difficulty implementing the incident strategy, and a factor for the socio/political concerns for the incident and the values at risk.



Extended Risk Assessments provide additional justification and validation of the decisions and actions associated with Management Action Points, resource allocations by Geographic Areas (GA), Management Area Coordination (MAC) groups, and individual agencies. The should reinforce the relative risk and organization assessments mentioned above.

Though organization is flexible, consider the elements in the relative risk assessment to ensure that this supporting document provides a focused collection of products, processes, and analyses that organizes information and assigns ratings to inform priorities and courses of action for decision-makers. An outline might include:

- An enumeration of Values at risk
- Reference Fuels, Climatology and Fire Behavior/Growth history as base line for current situation.
- A description of the current situation as it differs significantly from the reference conditions above.
- Expected fire behavior and growth based on analysis and judgement. Include statement of assumptions, limitations, and uncertainty in the analysis
- Anticipated impacts and effects based on the fire analysis
- Conclusions in support of the relative risk assessment.

Review and Update of Relative/Extended Risk, Organization, and Allocation assessments should be considered where:

- The fire has spread outside the planning area or outside the contours of the FSPro analysis used in the assessment
- The planning area is expanded
- Unexpected fire behavior is observed on the incident
- There weather forecast and outlook basis used in the assessment have changed significantly or expired.
- The analysis horizon for the fire behavior outputs has expired

7.5.3 Incident Narratives

The fire behavior narrative is an important document that captures key fire behavior information for the incident. It is often summarized (executive summary) for the final incident package. It is a dynamic document that is driven by the incident, the fire behavior, and analyses performed. It is a standard component of a fire behavior documentation package.

This may include representative RAWS sites, assumptions/limitations specific to the incident, local observations, or other relevant information that assisted with your analysis and interpretation.

While it does not have a specific format / template, there are elements common to most fires. An example is shown here:

- Heading with Incident Name, Period of Record, and Author
- Fire Weather/Climatology
- Fuels and Fire Danger
- Fire Behavior
- Significant Analysis
- Chronology of Fire Behavior Events

7.5.4 Documentation Records

Fire Behavior Documentation Package

A. Fire Behavior inputs and outputs specific to Behave or model used
   1. Worksheets (completely filled out with times and dates)
   2. Assumptions
   3. Index of runs and names
B. Maps (labeled with dates and times)
   1. Fire spread projections
   2. Fuel model
   3. Points of concern/values at risk/MMAs/M.A.P.s
C. Unit logs (ICS 214)
D. Outline of information provided in briefings
E. Fire behavior forecasts (validated) and any updates or supplements
   1. Document actual conditions and fire activity
F. Specific events (with time frames)
   1. Change from wildland fire use to wildfire; time frames
   2. Significant events
   3. Unforecasted weather events and resulting impacts on fire behavior
   4. Special or specific operational plans
   5. Special prescriptions
   6. Long range forecasts
G. Reference materials used during the assignment
H. Sources of data and why particular data sets were used or not used
I. Risks assessed and why, and what the consequences may be
J. Notification (who/when/ and how) of changes in predictions
K. Fire Behavior Chronology and Narrative

The package needs to support and describe the rationale behind your recommendations and explain how you choose to deal with conflicting information. All information needs to have the incident name, date/time, your name, and any other pertinent information on it. All documents need to be in a format the can be preserved as required by national documentation standards.

Electronic Fire Behavior Documentation

Any or all of the Fire Behavior Documentation may be produced and submitted in electronic format.

Ensure, if the documentation is a mix of paper and electronic records, that the file naming conventions are consistent and that they are organized in a meaningful way.

File formats are becoming less proprietary, but make sure that the format is in a common format and readily readable by other users and their computers. Highly formatted documents should be saved in PDF format as well as in the original.

Document desktop software name, vendor, and version. Consider including the install file.

Integrate files into the incident digital record and keep a copy of your submissions.

7.5.5 Briefing guidelines and products

Fireline Briefing Checklist (Situation)

- Fire name, location, map orientation, other incidents in the area
- Terrain influences
- Fuel Types and conditions
- Fire Weather (previous, current, and expected) including changes in winds, temperature, RH, cloud cover, and significant events
- Fire Behavior (previous, current, and expected) times and thresholds for active behavior, significant spread and flame length issues,

Fire Behavior Forecast

Incident Briefing Outline

7.6 References

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8. Fire Danger/NFDRS

8.1 Fire Danger Background

Fire Danger ratings are an effective part of daily risk rating and operational preparedness for fire management agencies across the world. Chapter 10 (Preparedness) of the Interagency Standards for Fire and Fire Aviation Operations outlines processes and resources applied in the development of standard Fire Danger Operating Plans.

Included in Fire Danger Operating Plans are:

- Specification of fire danger ratings
- Identification of climatological thresholds for administrative purposes. Default thresholds include the 90th and 97th percentile values for key indices in the applied system. The Bureau of Land Management (Department of Interior) uses the 80th and 95th percentiles instead.
- Communication of those danger ratings, including both internal and external forms.

Some valuable links:

- Weather Information Management System (WIMS)
- Wildland Fire Assessment System (WFAS)
- NFDRS Pocket Cards
- National Interagency Coordination Center Predictive Services

A variety of fire weather systems are applied in danger rating around the US. There are primarily two systems used in fire danger operating plans.

US National Fire Danger Rating System (NFDRS):

First introduced in 1964, NFDRS has been updated in 1972, 1978, 1988, and now 2016 to integrated newer science and improved processing. This guide will compare important aspects of the 1978, 1988, and 2016 versions, detail important outputs, and describe primary components and indices. More information about the system and the latest update to it can be found at:

https://www.wfas.net/nfdrs2016/index.php/en/

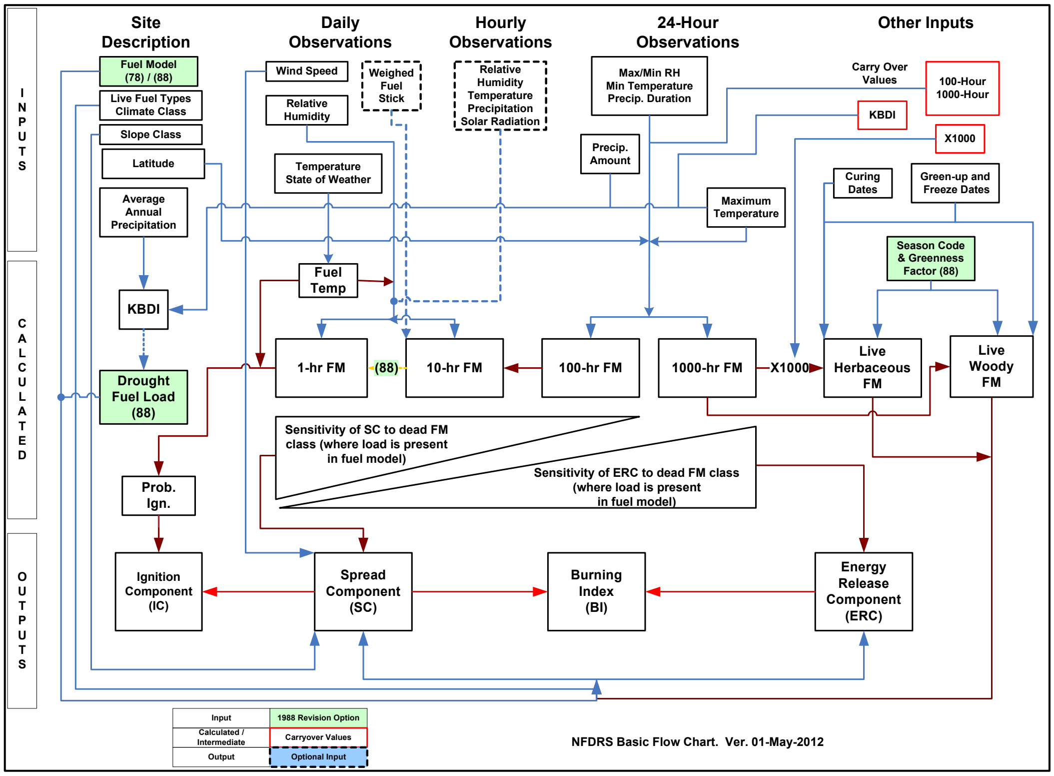
CFFDRS Fire Weather Index (FWI) System

Introduced in Canada in 1970. Implemented in Alaska and the lake states of Michigan, Minnesota, and Wisconsin in the early 1990s. Details about CFFDRS are included in a separate section of this guide. These websites provide data access

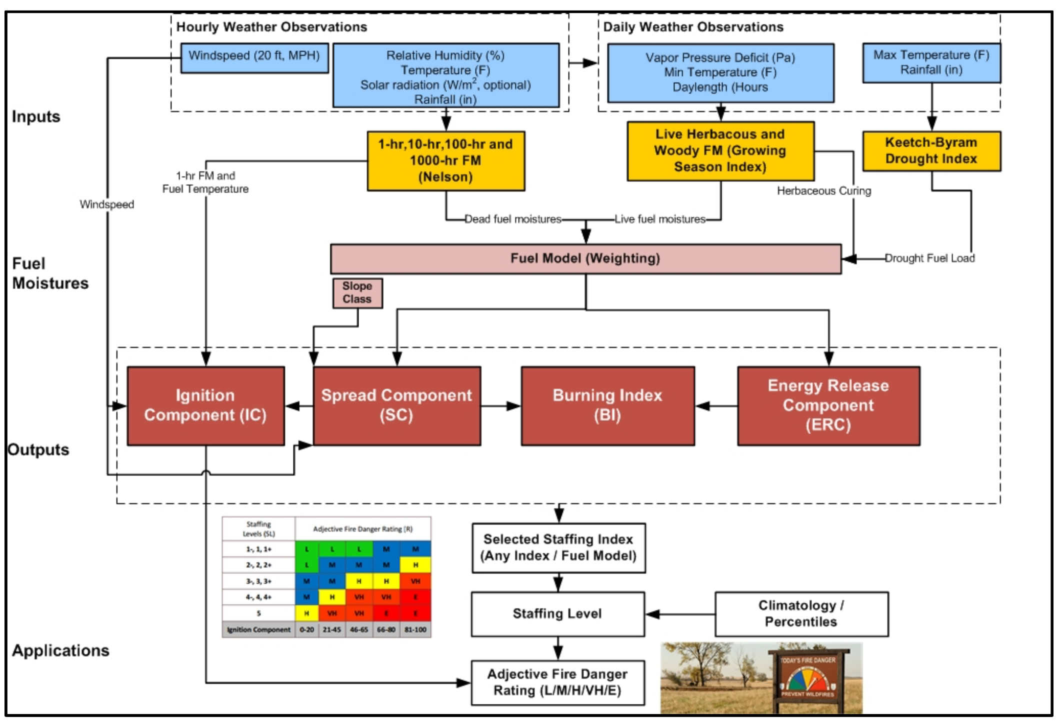
- Alaska and Great Lakes FWI

Other tools, formulations, and applications are used locally across the country. Some examples are highlighted later in this section.

8.1.1 78/88 Version NFDRS Structure



8.1.2 2016 Version NFDRS Structure



8.1.3 NFDRS Version Comparison

Category	78 Version	88 Version	2016 Version
Fuel Models and Settings	20 NFDRS specific fuel models Grass identified as annual or perennial Shrub type not detailed	Specific revisions to 3 of the 78 Version fuel models (C, E, and N) Grass identified as annual or perennial Shrubs identified as evergreen or deciduous	Reduction to 5 new 2016 Version NFDRS specific fuel models (V, W, X, Y, Z) Grass type not detailed Shrub type not detailed
Climate Class	Used to determine dormant 100h, 1000h, and live fuel moistures Used to specify duration of greenup process and influence curing rates	Used to determine dormant 100h, 1000h, and live fuel moistures	Used to determine dormant 100h, 1000h, and live fuel moistures
Manual Inputs	Observation type Snow Flag Wet Fuel Flag Greenup/Freeze Flag State of the Weather	Observation type Snow Flag Wet Fuel Flag Season 1h = 10h? Daily Herb & Woody Greenness Factor State of the Weather	Observation Type Snow Flag
1h & 10h	Fosberg-71 Model	Fosberg-71 Model	Nelson Model
100h & 1000h	Fosberg-71 Model	Fosberg-81 Model	Fosberg-81 Model
Herbaceous and Woody Fuel Moisture Content	Herb fuels classified as dead when dormant. Transition from dormant/dead fuel moisture to live/full greenup based on climate class in spring 1000hr based live moisture trend and load transfer	Herb fuels classified as dead when dormant. Season/Greenness factor based live fuel moisture trend/load transfer unless fuels declared dormant.	Herb fuels classed as dead when dormant. Growing Season/Live Fuel Index based moisture trend and load transfer
SC, IC, ERC, BI	Models unchanged. Outputs will vary based on differences from new fuel moisture models and new fuel model definitions.		

8.2 NFDRS Station Catalog (Site Settings)

8.2.1 NFDRS Fuel Model

Crosswalk Between 2016 and 78/88 Version Fuel Models

Carrier Fuel Category	NFDRS 2016 Fuel Model	Equivalent NFDRS 78/88 Fuel Model
Grass	V	A, L, T
Grass / Shrub	W	C, D, R, S
Brush	X	B, F
Forest	Y	G, H, N, P, O, Q, U, E
Slash	Z	I, J, K

78/88 NFDRS Fuel Model Definitions (* 1988 Version Fuel Model Revisions)

Carrier	Fuel Model	Fuel Model Name	1hr Load t/ac	10hr Load t/ac	100hr Load t/ac	1000hr Load t/ac	Herb Load t/ac	Woody Load t/ac	Total Load t/ac	1hr SAV	Herb SAV	Woody SAV	Bed Depth ft	Moist Extinct %	Heat Cntnt btu/lb
GR	A	Western Annual Grasses	0.2	--	--	--	.03	--	0.5	3000	3000	--	0.8	15	8000
GR	L	Western Perennial Grasses	0.25	--	--	--	0.5	--	0.75	2000	2000	--	1.0	15	8000
GR	V	2016 Grass													
GS	C*	Pine Grass Savanna	0.4	1.0	--	--	0.8	0.5 (*0.8)	2.1	2000	2500	1500	0.75	20	8000
GS	N*	Sawgrass	1.5	1.5	--	--	--	2.0	5.0	1600	--	1500	3.0	25 (*40)	8700
GS	S	Tundra	0.5	0.5	0.5	0.5	0.5	0.5	3.0	2500	1500	1200	0.4	25	8000
GS	T	Sagebrush Grass	1.0	0.5	--	--	0.5	2.5	4.5	2500	2000	1500	1.25	15	8000
GS	W	2016 Grass/Shrub													
SH	B	California Mixed Chaparral	3.5	4.0	0.5	--	--	11.5	19.5	700	--	1250	4.5	15	9500
SH	O	High Pocosin	2.0	3.0	3.0	2.0	--	7.0	17.0	1500	--	1500	4.0	30	9000
SH	F	Intermediate Brush	2.5	2.0	1.5	--	--	9.0	15.0	700		1250	4.5	15	9500
SH	Q	Alaskan Black Spruce	2.0	2.5	2.0	1.0	0.5	4.0	12.0	1500	1500	1200	3.0	25	8000
SH	D	Southern Rough	2.0	0.5	--	--	0.75	3.0	6.25	1250	1500	1500	2.0	30	9000
SH	X	2016 Shrub/Brush													
TU/L	H	Short Needle Pine (Normal Dead)	1.5	1.0	2.0	2.0	0.5	0.5	7.5	2000	2000	1500	0.3	20	8000
TU/L	G	Short Needle Pine (Heavy Dead)	2.5	2.0	5.0	12.0	0.5	0.5	22.5	2000	2000	1500	1.0	25	8000
TU/L	E*	Winter Hardwoods	1.5 (*1.0)	2.0	0.25	--	0.5 (*1.0)	0.5	4.75	2000	2000	1500	4.0*	25	8000
TU/L	R	Summer Hardwoods	0.5	0.5	0.5	--	0.5	0.5	2.5	1500	2000	1500	0.25	25	8000
TU/L	U	Western Long Needle Conifer	1.5	1.5	1.0	--	0.5	0.5	5.0	1750	2000	1500	0.5	20	8000
TU/L	P	Southern Pine Plantation	1.0	1.0	0.5	--	0.5	0.5	3.5	1750	2000	1500	0.4	30	8000
TU/L	Y	2016 Forest	2.5	2.2	3.6	8.6		0.2							
SB	K	Light Logging Slash	2.5	2.5	2.0	2.5	--	--	9.5	1500	--	--	0.6	25	8000
SB	J	Intermediate Logging Slash	7.0	7.0	6.0	5.5	--	--	25.5	1500	--	--	1.3	25	8000
SB	I	Heavy Logging Slash	12.0	12.0	10.0	12.0	--	--	46.0	1500	--	--	2.0	25	8000
SB	Z	2016 Slash													

NFDRS Grass Models

2016 Fuel Model V

Fuel Model A – This fuel model represents western grasslands vegetated by annual grasses and forbs. Brush or trees may be present but are very sparse, occupying less than one-third of the area. Examples of types where Fuel Model A should be used are cheatgrass and medusa head. Open pinyon-juniper, sagebrush-grass, and desert shrub associations may appropriately be assigned this fuel model if the woody plants meet the density criteria. The quantity and continuity of the ground fuels vary greatly with rainfall from year to year.

Fuel Model L – This fuel model is meant to represent western grasslands vegetated by perennial grasses. The principal species are coarser and the loadings heavier than those in Model A fuels. Otherwise the situations are very similar; shrubs and trees occupy less than one-third of the area. The quantity of fuels in these areas is more stable from year to year. In sagebrush areas Fuel Model T may be more appropriate.

NFDRS Grass/Shrub Models

2016 Fuel Model W

Fuel Model C – Open pine stands typify Model C fuels. Perennial grasses & forbs are the primary ground fuel but there is enough needle litter & branchwood present to contribute significantly to the fuel loading. Some brush & shrubs may be present but are of little consequence. Types covered by Fuel Model C are open, longleaf, slash, ponderosa, Jeffery, & sugar pine stands. Some pinyon-juniper stands may qualify.

Fuel Model D – This fuel model is specifically for the palmetto-gallberry understory-pine association of the southeast coastal plains. It can also be used for the so-called "low pocosins" where Fuel Model O might be too severe. This model should only be used in the Southeast because of the high moisture of extinction associated with it.

Fuel Model N – This fuel model was constructed specifically for the sawgrass prairies of south Florida. It may be useful in other marsh situations where the fuel is coarse and reed like. This model assumes that one-third of the aerial portion of the plants is dead. Fast-spreading, intense fires can occur over standing water.

Fuel Model S – Alaskan and alpine tundra on relatively well-drained sites fit this fuel model. Grass and low shrubs are often present, but the principal fuel is a deep layer of lichens and moss. Fires in these fuels are not fast spreading or intense, but are difficult to extinguish.

<u>Fuel Model T</u> – The sagebrush-grass types of the Great Basin and the Intermountain West are characteristic of Fuel Model T. The shrubs burn easily and are not dense enough to shade out grass and other herbaceous plants. The shrubs must occupy at least one-third of the site or the A or L fuel models should be used. Fuel Model T might be used for immature scrub oak and desert shrub associations in the West and the scrub oak-wire grass type of the Southeast.

<u>NFDRS Timber Understory and Timber Litter Models</u>

<u>2016 Fuel Model Y</u>

<u>Fuel Model H</u> – Used for short-needled conifers (white pines, spruces, larches, & firs). In contrast to FM G fuels, FM H describes a healthy stand with sparse undergrowth and a thin layer of ground fuels. Fires in FM H are typically slow spreading and are dangerous only in scattered areas where the downed woody material is concentrated.

<u>Fuel Model G</u> – Used for dense conifer stands where there is a heavy accumulation of litter & down woody material. They are typically over mature & may be suffering insect, disease, & wind or ice damage—natural events that create a very heavy buildup of dead material on the forest floor. The duff & litter are deep and much of the woody material is >3” in diameter. The undergrowth is variable, but shrubs are usually restricted to openings. Types represented here are hemlock-Sitka spruce, coastal Douglas fir, and wind thrown or bug-killed stands of lodgepole pine & spruce.

<u>Fuel Model E</u> – Used after fall leaf fall for hardwood and mixed hardwood-conifer types where the hardwoods dominate. Fuel is primarily hardwood leaf litter. It best represents the oak- hickory types & is a good choice for northern hardwoods and mixed forests of the Southeast. In high winds, the fire danger may be underrated because rolling and blowing leaves are not accounted for.

<u>Fuel Model R</u> – This fuel model represents hardwood areas after the canopies leaf out in the spring. It is the growing season version of FM E. It should be used during the summer in all hardwood and mixed conifer-hardwood stands where more than half of the overstory is deciduous.

<u>Fuel Model U</u> – This fuel model represents the closed stands of western long-needled pines. The ground fuels are primarily litter and small branchwood. Grass and shrubs are precluded by the dense canopy but may occur in the occasional natural opening. Fuel Model U should be used for ponderosa, Jeffery, sugar pine stands of the West and red pine stands of the Lake States. Use FM P for southern pine plantations.

Fuel Model P – Closed, thrifty stands of long- needled southern pines are characteristic. A 2-4 inch layer of lightly compacted needle litter is the primary fuel. Some small diameter branchwood is present but the density of the canopy precludes more than a scattering of shrubs/grass. FM P has the high moisture of extinction characteristic of the Southeast. The corresponding model for other long-needled pines is FM **U**.

NFDRS Brush/Shrub Models

2016 Fuel Model X

Fuel Model B – Mature, dense fields of brush six feet or more in height is represented by this fuel model. One-fourth or more of the aerial fuel in such stands is dead. Foliage burns readily. Model B fuels are potentially very dangerous, fostering intense, fast-spreading fires. This model is for California mixed chaparral, generally 30 years or older. The F model is more appropriate for pure chamise stands. The B model may also be used for the New Jersey pine barrens.

Fuel Model O – The O fuel model applies to dense, brush like fuels of the Southeast. In contrast to B fuels, O fuels are almost entirely living except for a deep litter layer. The foliage burns readily except during the active growing season. The plants are typically over six feet tall and are often found under open stands of pine. The high pocosins of the Virginia, North and South Carolina coasts are the ideal of Fuel Model O. If the plants do not meet the 6- foot criteria in those areas, Fuel Model D should be used.

Fuel Model F – Fuel Model F represents mature closed chamise stands and oak brush fields of Arizona, Utah, and Colorado. It also applies to young, closed stands and mature, open stands of California mixed chaparral. Open stands of pinyon-juniper are represented; however, fire activity will be overrated at low wind speeds and where ground fuels are sparse.

Fuel Model Q – Upland Alaska black spruce is represented by Fuel Model Q. The stands are dense but have frequent openings filled with usually flammable shrub species. The forest floor is a deep layer of moss and lichens, but there is some needle litter and small diameter branchwood. The branches are persistent on the trees, and ground fires easily reach into the crowns. This fuel model may be useful for jack pine stands in the Lake States. Ground fires are typically slow spreading, but a dangerous crowning potential exists. Users should be alert to such events and note those levels of SC and BI when crowning occurs.

NFDRS Slash & Blowdown Models

2016 Fuel Model Z

Fuel Model I – Fuel Model I was designed for clear-cut conifer slash where the total loading of materials less than six inches in diameter exceeds 25 tons/acre. After settling and the fines (needles and twigs) fall from the branches, Fuel Model I will overrate the fire potential. For lighter loadings of clear-cut conifer slash use Fuel Model J, and for light thinnings and partial cuts where the slash is scattered under a residual overstory, use Fuel Model K.

Fuel Model J – This model complements Fuel Model I. It is for clear-cuts and heavily thinned conifer stands where the total loading of material less than six inches in diameter is less than 25 tons per acre. Again as the slash ages, the fire potential will be overrated.

Model K – Slash fuels from light thinnings and partial cuts in conifer stands are represented by Fuel Model K. Typically the slash is scattered about under an open overstory. This model applies to hardwood slash and to southern pine clear-cuts where loading of all fuels is less than 15 tons/acre.

8.2.2 Annual vs Perennial Grass (78/88 Versions only)

The loading of fine fuels associated with **annual grasses** shift from live to dead and stays there for the duration of the season. For **perennial grasses**, the shift from live to dead is much and may even stop or reverse if the right combinations of temperature and precipitation occur during the season.

8.2.3 Deciduous vs Evergreen Shrub (88 Version only)

In the 1988 revision to the NFDRS, separate equations were developed for deciduous and evergreen shrub vegetation, requiring users to enter a code indicating whether their local shrub vegetation is deciduous (D) or evergreen (E)

8.2.4 Climate Class Assumptions

				Dormant FM Minimums			78 Transition rates, in days	
Climate Class	**Name**	**Ecology**	**Description**	**100h**	**1000h**	**Woody**	**Greenup**	**Curing**
1	Arid & Semi-Arid	Desert	Sonoran, Mohave, Short grass prairie, interior west scrub lands	10%	15%	50%	7 days	Controlled by 1000hr fuel moisture between Full Greenup and Dormancy
2	Sub-humid	Steppe & Savanna	AK interior, chaparral, oak and pine woodlands	15%	20%	60%	14 days	
3	Sub-humid & Humid	Savanna & Forest	Bluestem prairie, grass-oak hickory savanna, Eastern US, western forests	20%	25%	70%	21 days	
4	Wet	Rain forest	Coastal forests	25%	30%	80%	28 days	

8.2.5 Slope Class Setting

Slope Class	Slope Range	Effective Midpoint	Slope Coefficient
1	0-25	22.5	0.267
2	26-40	31.8	0.533
3	41-55	44.5	1.068
4	56-75	63.6	2.134
5	> 75	90.0	4.273

8.3 NFDRS System Inputs and Outputs

8.3.1 Observations and Forecasts

Fire Weather Observations are collected and maintained according to standards established in the Interagency Wildland Fire Weather Station Standards and Guidelines

Lightning Activity Level (LAL)

Scale	Description
LAL 1	No Thunderstorms
LAL 2	Isolated thunderstorms. Light rain will occasionally reach the ground. Lightning is very infrequent, 1-5 cloud to ground strikes in a 5 minute period.
LAL 3	Widely scattered thunderstorms. Light to moderate rain will reach the ground. Lightning is infrequent, 6-10 cloud to ground strikes in a 5 minute period.
LAL 4	Scattered thunderstorms. Moderate rain is commonly produced. Lightning is frequent, 11-15 cloud to ground strikes in a 5 minute period
LAL 5	Numerous thunderstorms. Rainfall is moderate to heavy. Lightning is frequent and intense, greater than 15 cloud to ground strikes in a 5 minute period.
LAL 6	Same as LAL 3 except thunderstorms are dry (no rain reaches the ground). This type of lightning has the potential for extreme fire activity and is normally highlighted in fire weather forecasts with a Red Flag Warning.

8.3.2 Primary System Components & Indices

Ignition Component (IC) - The Ignition Component is a rating of the probability that a firebrand will cause a fire requiring suppression action. Expressed as a probability; it ranges on a scale of 0 to 100. An IC of 100 means that every firebrand will cause an "actionable" fire if it contacts a receptive fuel. Likewise, an IC of 0 would mean that no firebrand would cause an actionable fire under those conditions. Note the emphasis is on action

Spread Component (SC) - The Spread Component is a rating of the forward rate of spread of a headfire. Deeming, et al, (1977), states that "the spread component is numerically equal to the theoretical ideal rate of spread expressed in feet-per-minute. Highly variable from day to day, the Spread Component is expressed on an open-ended scale; thus it has no upper limit.

Energy Release Component (ERC) - The Energy Release Component is a number related to the available energy (BTU) per unit area (square foot) within the flaming front at the head of a fire. Daily variations in ERC are due to changes in moisture content of the various fuels present, both live and dead. Since this number represents the potential “heat release” per unit area in the flaming zone, it can provide guidance to several important fire activities. It may also be considered a composite fuel moisture value as it reflects the contribution that all live and dead fuels offer to potential fire intensity. It should also be pointed out that the ERC is a cumulative or “build-up” type of index. As live fuels cure and dead fuels dry, the ERC values get higher thus providing a good reflection of drought conditions. The scale is open-ended or unlimited and, as with other NFDRS components, is relative. Conditions producing an ERC value of 24 represent a potential heat release twice that of conditions resulting in an ERC value of 12. As a reflection of its composite fuel moisture nature, the ERC becomes a relatively stable evaluation tool for planning decisions that might need to be made 24 to 72 hours ahead of an expected fire decision or action.

Burning Index (BI) – The Burning Index is a number related to the contribution of fire behavior to the effort of containing a fire. The BI is derived from a combination of Spread and Energy Release Components. It is expressed as a numeric value closely related to the flame length in feet multiplied by 10. The scale is open ended which allows the range of numbers to adequately define fire problems, even in time of low to moderate fire danger. Table 1, adapted from Deeming et al (1977) gives several cross references that relate BI to fireline intensity and flame length with narrative comments relative to the effects on prescribed burning and fire suppression activities. It’s important to remember that computed BI values represent the near upper limit to be expected on the rating area. In other words, if a fire occurs in the worst fuel, weather and topography conditions of the rating area, these numbers indicate its expected fireline intensities and flame length. Studies have indicated that difficulty of containment is not directly proportional to flame length alone but rather to fireline intensity, the rate of heat release per unit length of fireline, (Byram 1959). The use of fireline intensity as a measure of difficulty shows that the containment job increases more than twice as fast as BI values increase. It is still safe to say that flame length is related to fireline intensity because BI is based on flame length

Lightning Occurrence Index (LOI) – The Lightning Occurrence Index is a numerical rating of the potential occurrence of lightning-caused fires. It is intended to reflect the number of lightning caused fires one could expect on any given day. The Lightning Occurrence is scaled such that a LOI value of 100 represents a potential of 10 fires per million acres. It is derived from a combination of Lightning Activity Level (LAL) and Ignition Component. To effectively develop this index the user must perform an extensive analysis to develop a local relationship between thunderstorm activity level and number of actual fire starts that result. Since our ability to accurately quantify thunderstorm intensity is limited it is difficult to develop a relationship between activity and fire starts. Thus the Lightning Occurrence Index is seldom used in fire management decisions. Local fire managers should however monitor the lightning activity level provided by the National Weather Service and with a little experience can develop their own rating of lightning fire potential.

Human Caused Fire Occurrence Index (MCOI) – This is a numeric rating of the potential occurrence of human-caused fires. Similar to the Lightning Occurrence Index, this value is intended to reflect the number of human-caused fires one could expect on any given day. It is derived from a measure of daily human activity and its associated fire start potential, the human caused fire risk input, and the ignition component. The MCOI is scaled such that the number is equal to 10 times the number of fires expected that day per million acres. An index value of 20 represents a potential of 2 human caused fires per million acres that day if the fuel bed was receptive for ignition. The original developers of the National Fire Danger Rating System recognized that "where the total fires per million acres average twenty or fewer, the evaluations are questionable". This has been validated through application. As with the Lightning Occurrence Index, the Human-caused Fire Occurrence Index requires considerable analysis to establish a local relationship between the level of human activity and fire starts. Since human activity is fairly constant throughout the season and human-caused fire occurrence in, for example, the Pacific Northwest, is relatively low in terms of fires per million acres per day, most analyses result in very low risk inputs that don't change much from day to day. Few fire managers, if any, are using this index in making day to day decisions.

Fire Load Index (FLI) – Fire Load Index is a rating of the maximum effort required to contain all probable fires occurring within a rating area during the rating period. The FLI was designed to be the end product of the NFDRS – the basic preparedness or strength of-force pre-suppression index for an administrative unit. It was to be used to set the readiness level for the unit. It focuses attention upon the total fire containment problem. Because the FLI is a composite of the various components and indexes of the NFDRS, including the local lighting and human caused fire risk inputs, the comparability of values varied significantly from one unit to another. To be useful managers must establish the relationship between the FLI calculated for their unit and the true fire containment effort needed. The FLI is represented as a number on a scale of 1-100. It provides no specific information as to the nature of the potential fire problem as individual indexes and components do. Because the Fire Load Index is a composite of several pieces of the NFDRS, its utility is impacted by of the inherent weaknesses of the individual components and indexes. Very few fire management decisions are made based on the Fire Load Index alone.

Keetch-Byram Drought Index (KBDI) - This index is not an output of the National Fire Danger Rating System itself but is often displayed by the processors used to calculate NFDRS outputs. KBDI is a stand-alone index that can be used to measure the effects of seasonal drought on fire potential. The actual numeric value of the index is an estimate of the amount of precipitation (in 100ths of inches) needed to bring the soil back to saturation (a value of 0 is complete saturation of the soil). Since the index only deals with the top 8 inches of the soil profile, the maximum KBDI value is 800 or 8.00 inches of precipitation would be needed to bring the soil back to saturation. The Keetch-Byram Drought Index's relationship to fire danger is that as the index value increases, the vegetation is subjected to increased stress due to moisture deficiency. At higher values desiccation occurs and live plant material is added to the dead fuel loading on the site. Also an increasing portion of the duff/litter layer becomes available fuel at higher index values. If you are using the 1978 fuel models, KBDI values can be used in conjunction with the National Fire Danger Rating System outputs to aid decision making. If you are using the modified NFDRS fuel models that were developed in 1988, KBDI values are a required input to calculate daily NFDRS outputs. Since most fire danger stations are not being operated when the soil is in a saturated condition, it is necessary to estimate what the KBDI value is when daily observations are began. The technical documentation describing the KVBDI includes methodology to estimate the initiating value is included in the attached reference list. Most processors include a default initiation value of 100.

8.3.3 Wildland Fire Assessment System (WFAS)

WFAS (http://wfas.net/) provides public access to standard ***Fire Potential/Danger*** depictions, ***Fire Weather*** information, ***Fuel Moisture/Drought*** products, and assorted ***Experimental Products*** produced by the Rocky Mountain Research Station's Fire, Fuel and Smoke Science Program

Operating with fire weather observations from WIMS (4.3.4), gridded forecasts from NWS National Digital Forecast Database (NDFD), and gridded fire danger climatology dating to 1979.

8.3.4 Weather Information Management System (WIMS)

NAP Access Portal (https://nap.nwcg.gov/NAP/#) requires login and provides authorized access for management of RAWS station catalogs, observations, NFDRS calculations, and source data for other portals such as the Enterprise Geospatial Portal (EGP) and Wildland Fire Assessment System (WFAS)

WIMS Users Guide (https://famit.nwcg.gov/applications/WIMS/userguide)

8.3.5 Pocket Cards

FAM-IT Portal: https://famit.nwcg.gov/applications/WIMS/PocketCards provides access to background, instructions, standards, and approved cards throughout the US.

The Fire Danger Pocket Card provides a format for interpreting and communicating key index values provided by the National Fire Danger Rating System. The objective is to lead to greater awareness of fire danger and subsequently increased firefighter safety. The Pocket Card provides a description of seasonal changes in fire danger in a local area. It is useful to both local and out-of-area firefighters.

The Pocket Card has very important day-to-day "pre-suppression" uses. When the morning and afternoon weather is read each day, the actual and predicted indices are announced. Firefighters can reference their card and assess where today falls in the range of historical values for danger-rating. This important information should be discussed at morning crew meetings, tailgate safety meetings, incident briefings, etc.

Local fire management personnel can produce the cards using Fire Family Plus. Cards should be developed locally with local fire management involvement to meet local fire management needs.

8.4 Interagency Predictive Services

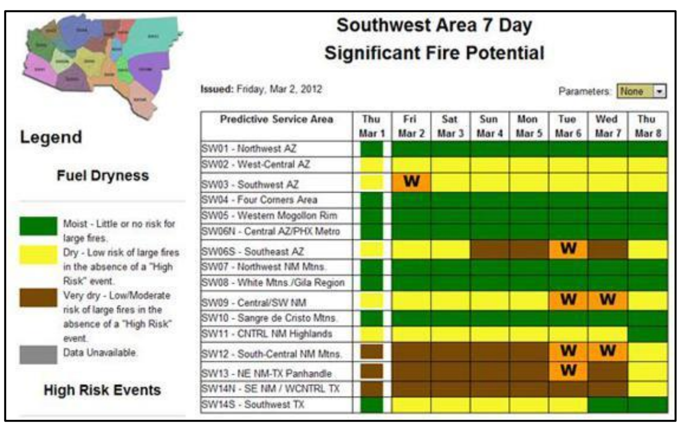
During the active fire season, the [National Interagency Coordination Center (NICC)]() and each geographic area predictive service office is staffed 7 days a week to support the assessment needs of fire program managers, incident personnel, and groups coordinating regional fire management resources.

All the geographic area predictive service products can be referenced from the National Interagency Coordination Center (NICC) outlooks page:

http://www.predictiveservices.nifc.gov/outlooks/outlooks.htm

A National ***7-Day Significant Fire Potential Outlook*** is produced each day:

http://psgeodata.fs.fed.us/forecast/#/outlooks?state=map



This 7-day outlook also includes forecasts for the weather elements, fuel moistures, and fire danger indices that are used to produce these potential classifications. These 7-day forecasts represent averages for areas defined by the geographic area to be climatologically distinct.

Other standard products include daily, monthly, and seasonal assessments. Several produce multi-media briefings that can be linked from the outlooks page.

8.5 Other Online Fire Danger Resources

- Alaska Fire Weather Index (FWI)
- Florida Wildland Fire Danger Index (FDI)
- Georgia Forestry Commission Fire Weather System
- Great Lakes Fire Weather Index (FWI)
- Maine Wildfire Danger Report
- Michigan DNR Wildland Fire Application
- Minnesota DNR Wildfire Information Center
- New York State Fire Danger Map
- North Carolina Fire Weather Intelligence Portal
- OK-Fire, Oklahoma Mesonet
- Santa Ana Wildfire Threat Index

8.6 Fire Danger References

8.6.1 Online Resources

- Weather Information Management System (WIMS)
- Wildland Fire Assessment System (WFAS)
- NFDRS Pocket Cards
- US Interagency Predictive Services Outlooks

8.6.2 Publications

Andrews, P. L., and L. S. Bradshaw, D. Bunnell, G. Curcio. 1997. Fire Danger Rating PocketCard for Firefighter Safety. In Proceedings of the 2nd Symposium on Fire and Forest Meteorology.

Bradshaw, Larry S.; Deeming, John E.; Burgan, Robert E.; Cohen, Jack D compilers. The 1978 National Fire-Danger Rating System: technical documentation. General Technical Report INT-169. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984. 44 p.

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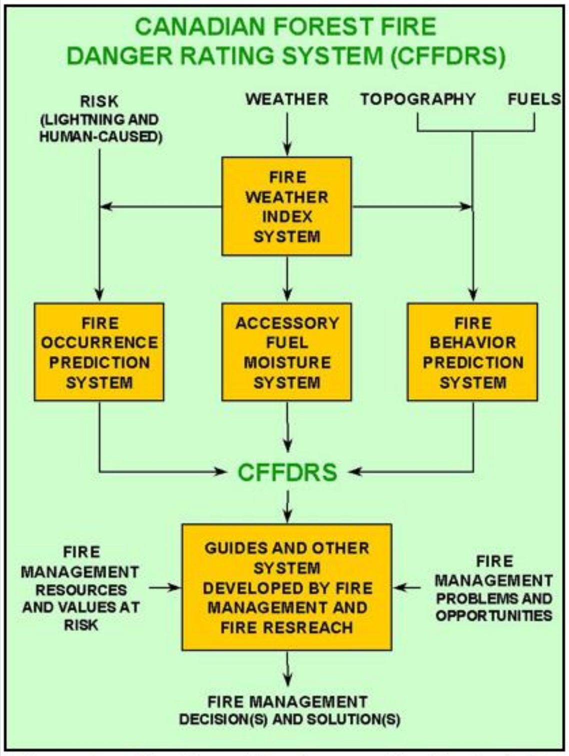
9. Canadian Forest Fire Danger Rating System

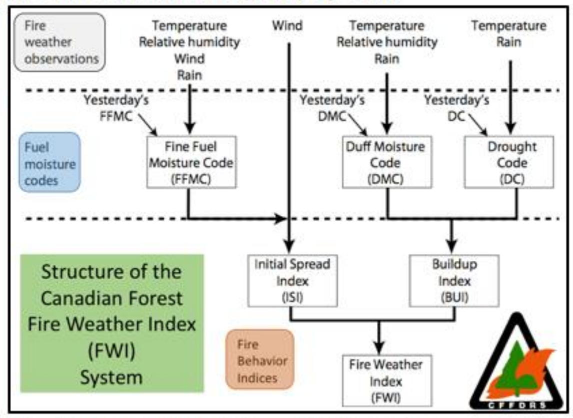
9.1 CFFDRS System Overview

The Canadian Forest Fire Danger Rating System, as shown in these flow charts, is designed as a comprehensive system of tools designed to evaluate environmental factors that influence the ignition, spread, and behavior of wildland fire.

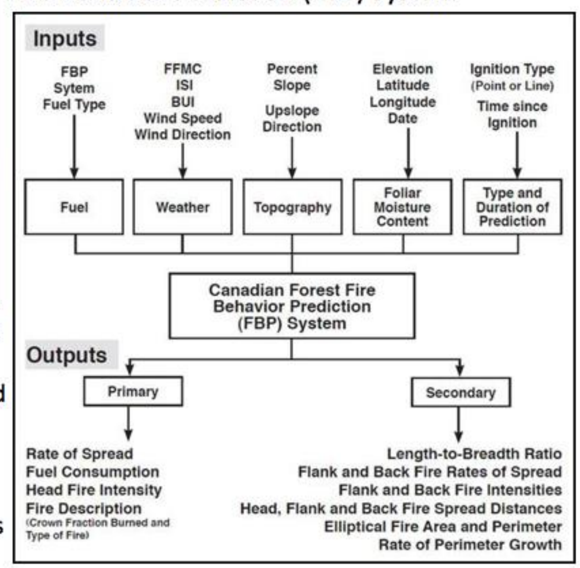


The system has its origins from early efforts dating to the 1920's. As currently configured, it was first conceived in 1968. The FWI system was developed and introduced across Canada in 1970. The FBP tools were released in 1984. Additional systems for fuel moisture (hourly FFMC, Grass Fuel Moisture) and ignition have followed. This guide is intended as a quick reference for US users.

Fire Weather Index (FWI) System



Fire Behavior Prediction (FBP) System



There are several important Distinctions for NFDRS and NFBPS Users:

9.1.1 Use of English Units

All the CFFDRS tools and references produced by the Canadian and Provincial governments, as well as applications produced internationally, use the metric system for all measured values. For the most part, measures referenced here are in English units to facilitate utility and use in the United States.

9.1.2 Wind Observations

CFFDRS Weather observations, provided to the system for both FWI and FBP calculations, generally conform to familiar fire weather standards. These standards can be reviewed in the weather guide referenced below. However, wind observation standards conform to the international 10m height as opposed to the NFDRS 20ft height standard.

CFFDRS models and tools do not expressly apply relationships between the standard 10m wind measurements and others that US users may be familiar with. Both 20ft and eye level winds are commonly referenced and reported from US RAWS observing locations and from the fireline. Further, windspeeds reported from Airport (ASOS) and provided in NWS weather forecasts generally report higher windspeed, where surrounding terrain is flat with little variation in vegetation height or structural interference and is highly correlated with forecast windspeed provided in the National Digital Forecast Database (Lawson and Armitage, 2008).

This table provides a quick reference to aid conversion between 10m, 20ft, unsheltered Eye Level (EL Op) observations, and Forecast/Airport winds.

Open Windspeed: Use only 10m For Effective Windspeed

Conversion Factors: **10m** = Fcst (Airport) x 0.7, **10m** = 20 ft * 1.12, **10 m** = Eye Level Open [EL Op] * 1.54

FCST	0	1	4	6	9	10	13	16	17	20	21	24	26	29	30	33	34	37	39	41	44
10m	0	1	3	4	6	7	9	11	12	14	15	17	18	20	21	23	24	26	27	29	31
20ft	0	1	3	4	5	6	8	10	11	13	13	15	16	18	19	21	21	23	24	26	28
EL Op	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

9.1.3 Fire Intensity Measures

A major adaptation in US tools and references (with uncertain validity) is the use of flame length for fire intensity outputs in the fire behavior tables. FBP outputs (kW/m) were converted to BTU/ft/sec using standard conversions and then to flame length using the formula:

$$Flame\ Length = .45 * "BTU/Ft/Sec"\text{^}.46$$

This table identifies the CFFBP Fire intensity thresholds in kW/m and the corresponding values in English units (BTU/ft/sec) and flame length in feet. These thresholds are consistent with commonly held flame length thresholds for fire safety interpretations.

Fire Intensity		Flame Length
kW/m	BTU/ft/sec	Feet
10	3	1
500	145	4
2000	578	8
4000	1156	12
10000	2891	18

9.2 Fire Weather Index System

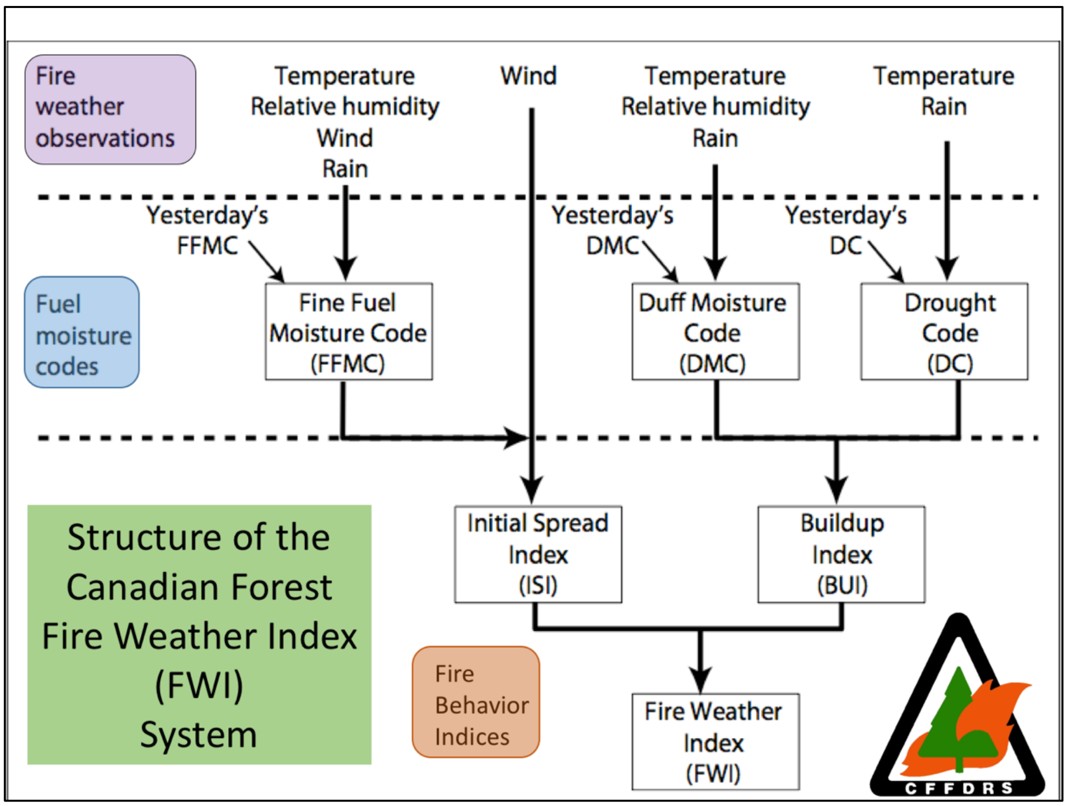
9.2.1 Introduction

Analogous in concept to the National Fire Danger Rating System (NFDRS), the FWI System depends solely on weather readings. Resulting fuel moisture codes and fire behavior indices are based on a single “standard” fuel type that can be described as a generalized pine forest, most nearly jack pine and lodgepole pine.

The Fire Weather Index System calls for weather observations to be collected from a standard observation site and time. Location standards can be found in the “Weather Guide for the Canadian Forest Fire Danger Rating System” (Lawson and Armitage, 2008). The system calls for observations to be taken at “solar” noon, when the sun is at its peak directly overhead.

Reference tools and current conditions are available to US users through:

- Field Guides: Alaska, Michigan, Minnesota
- Online Resources: Alaska Fire & Fuels Great Lakes Fire & Fuels
- Weather Guide for CFFDRS: https://cfs.nrcan.gc.ca/publications?id=29152



9.2.2 Fire Weather Index – NFDRS Crosswalk

This table provides the crosswalk between FWI weather inputs, fuel moisture codes, and fire behavior indices with their NFDRS counterparts.

FWI System	Elements	NFDRS 2016
Daily Observations Required (4) (at Solar Noon) Temperature Relative Humidity Windspeed Rainfall **Hourly Observations for GFMC** Add Solar Radiation	**Weather Observations**	**Hourly Observations Required (120)** Temperature Relative Humidity Windspeed Rainfall Solar Radiation
	Intermediate Weather Outputs	Max/Min Temperature Max/Min Relative Humidity Precipitation Duration Daylength Vapor Pressure Deficit (VPD) Growing Season Index (GSI)
Fine Fuel Moisture Code (FFMC) – (5-16hr Timelag) Grass Fuel Moisture Code (GFMC) – (not part of Daily FWI)	**Fine Fuel Moisture**	1 hr Fuel Moisture 10 hr Fuel Moisture
Duff Moisture Code (DMC) – (15 day or 360 hour Timelag)	**Intermediate Fuel Moisture**	100 hr Fuel Moisture Live Herbaceous Fuel Moisture (LHM)
Drought Code (DMC) (53 day or 1272 hour Timelag)	**Drought Indicators**	1000 hr Fuel Moisture Live Woody Fuel Moisture (LWM) Keetch-Byrum Drought Index (KBDI)
Initial Spread Index (ISI) Buildup Index (BUI) Fire Weather Index (FWI)	**Fire Behavior Outputs**	Ignition Component (IC) Spread Component (SC) Energy Release Component (ERC) Burning Index (BI)

9.2.3 FWI Fuel Moisture Codes

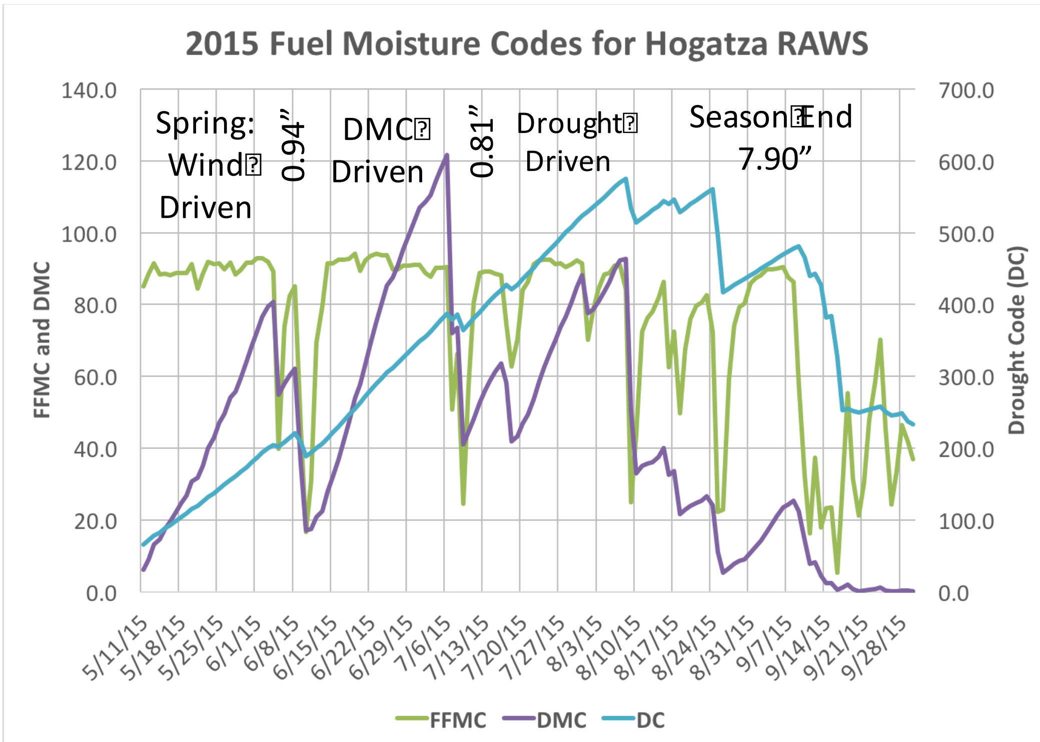
There are 3 fuel moisture categories, or codes, in the FWI system, compared to 7 found in NFDRS. These are generally represented as unitless codes instead of fuel moisture content (represented as a % of dry weight). They can be converted to moisture content, and in fact, are converted each day as part of the daily or hourly calculations.

The Fine Fuel Moisture Code (FFMC) represents fuel moisture of forest litter fuels under the shade of a forest canopy. It is intended to represent moisture conditions for shaded litter fuels, the equivalent of 16-hour timelag. It ranges from 0-101. Subtracting the FFMC value from 100 can provide an estimate for the equivalent (approximately 10h) fuel moisture content, most accurate when FFMC values are roughly above 80.

The Duff Moisture Code (DMC) represents fuel moisture of decomposed organic material underneath the litter. System designers suggest that it is represents moisture conditions for the equivalent of 15-day (or 360 hr) timelag fuels. It is unitless and open ended. It may provide insight to live fuel moisture stress.

The Drought Code (DC), much like the Keetch-Byrum Drought Index, represents drying deep into the soil. It approximates moisture conditions for the equivalent of 53-day (1272 hour) timelag fuels. It is unitless, with a maximum value of 1000. Extreme drought conditions have produced DC values near 800.

This example plot of all three moisture codes through a fire season demonstrates how fuel moisture codes rise as fuels dry out, and falls with precipitation and (primarily with FFMC) with moderating weather.



In this way, these fuel moisture codes can more easily provide visual comparisons with the associated fire behavior indices. Among them, the DMC and DC are effectively open ended codes with little chance environmental conditions will produce maximum values.

FFMC	96	95	94	93	92	91	90	89	88	87	86	85	84	83	82	81	80
10h-Sh	5	6	7	8	9	10	11	12	13	14	15	16	17	19	20	21	22
10h-Unsh	5		6	7		8	9		10	11	12		13	14		15	

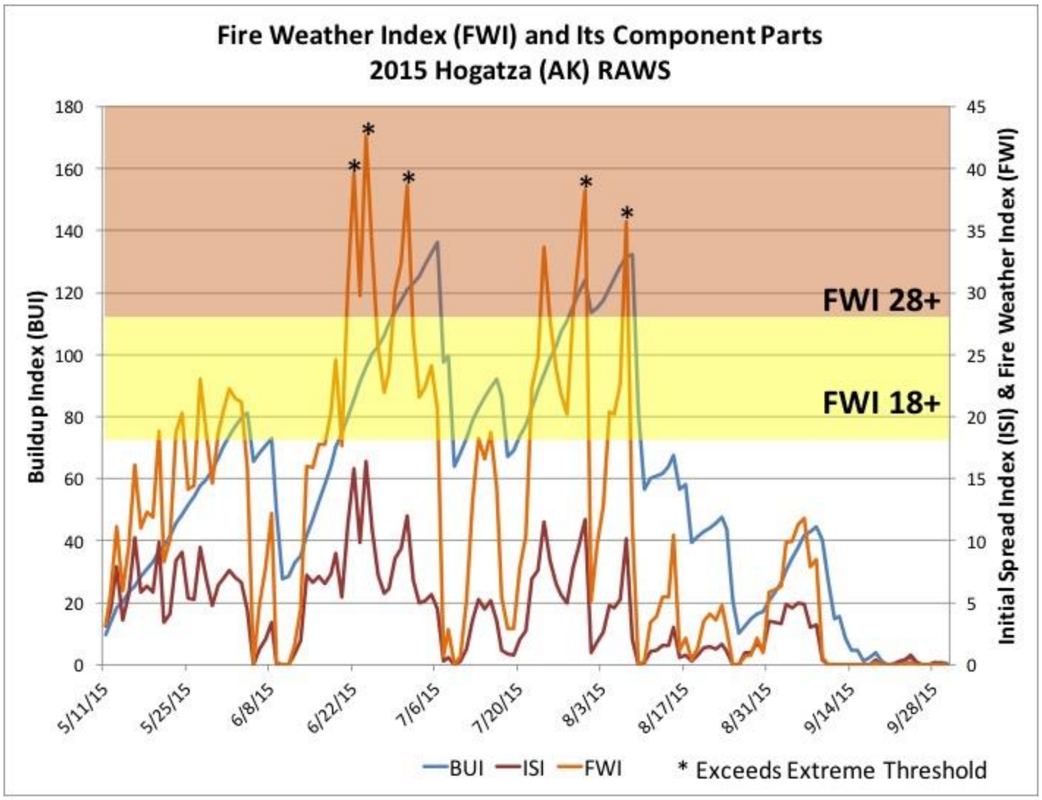
The FFMC, representing moisture conditions in shaded forest litter, is analogous to 10-hr fuel moisture estimates. This table suggests the conversion for both shaded (10h-Sh) and unshaded (10h-Unsh) fuel bed conditions:

9.2.4 FWI Fire Behavior Indices

There are 3 fire behavior indices in the FWI system:

- ***The Initial Spread Index (ISI)*** is analogous to the NFDRS Spread Component (SC). It integrates fuel moisture for fine dead fuels and surface windspeed to estimate a spread potential. ISI is a key input for fire behavior predictions in the FBP system. It is unitless and open ended.
- ***The Buildup Index (BUI)*** is analogous to the NFDRS Energy Release Component (ERC). It combines the current DMC and DC to produce an estimate of potential heat release in heavier fuels. It is unitless and open ended. In Alaska and the Lake States, it is the primary indicator of season severity during the growing season.
- ***The Fire Weather Index (FWI)*** integrates current ISI and BUI to produce a unitless index of general fire intensity potential. It is analogous to NFDRS Burning Index. With dry fuel conditions, it is a key indicator of extreme fire behavior potential. Again, unitless and open ended.

As shown in this graph, the FWI integrates the influences of spread (ISI) and fuel flammability (BUI) to produce a unitless index of potential fire intensity and prospect for extreme fire behavior.



9.2.5 Grass Fuel Moisture (GFM)

The GFM is a fourth fuel moisture category for grass fuel moisture specifically (Wotton, 2009). It is not part of the daily FWI system. Research in Ontario (Kidnie et.al, 2010) quantified the fuel moisture trends for grass fuels and established a grass fuel moisture model that is produced only with hourly data. Its corresponding Grass Fuel Moisture Code (GFMC), along with the FFMC, provides hourly estimates to represent diurnal and event based changes in fine fuel moisture as they occur.

Grass Fuel Moisture

- Based on research done in savanna grasses in Ontario
- Table shows Equilibrium Moisture Content
- Assumes that atmosphere unchanged for 2-3 hours.

CFFDRS Grass Fuel Moisture		Relative Humidity (%)							
SOL_{ef}	Temp	10%	20%	30%	40%	50%	60%	80%	100%
Overcast Or Shaded	41°F	10	13	16	17	19	21	25	38
	50°F	9	12	14	16	17	19	23	37
	59°F	8	11	13	15	16	17	23	37
	68°F	7	10	12	13	15	17	21	34
	77°F	6	8	10	12	14	15	20	32
	86°F	5	7	9	11	12	14	19	32
Broken, Clouds > 50% of sky	41°F	7	10	12	14	15	16	19	21
	50°F	6	9	11	13	14	15	17	20
	59°F	6	8	10	11	13	14	16	19
	68°F	5	7	9	10	12	13	15	17
	77°F	4	6	8	9	10	11	14	17
	86°F	3	5	6	8	9	10	13	16
Scattered Clouds < 50% of sky	41°F	5	8	10	11	12	13	15	17
	50°F	5	7	9	10	11	12	14	15
	59°F	4	6	7	9	10	11	13	14
	68°F	4	5	6	8	9	10	11	13
	77°F	3	4	5	6	7	8	10	12
	86°F	2	3	4	5	6	7	9	11
Clear Skies	41°F	4	6	7	8	9	10	12	13
	50°F	3	5	6	7	8	9	11	12
	59°F	3	4	5	6	7	8	9	11
	68°F	3	4	4	5	6	7	8	10
	77°F	2	3	4	4	5	6	7	9
	86°F	2	2	3	3	4	5	6	7

9.2.6 Other Considerations

Diurnal Variations

There is an hourly version of the Fine Fuel Moisture Code that reflects variability influenced by temperature and humidity changes throughout the day and night. Using the corresponding, locally observed windspeed, updated values for Initial Spread Index and Fire Weather Index may also be produced.

Seasonal Start-up and Resumption after Interruption in Observations

Daily records are generally started as soon as there is measurable fire danger in the spring. In Alaska, this is defined as the third day after snow has essentially left the area to which the fire danger rating applies.

Default seasonal start-up values are 85 for FFMC, 6 for DMC, and 15 for DC. If daily observations are interrupted during the season and missing observations cannot be estimated, fuel moisture codes must be estimated for the last day of missing observations and used as “yesterday” fuel moisture codes for the newly resumed weather observation.

9.3 Fire Behavior Prediction (FBP) System

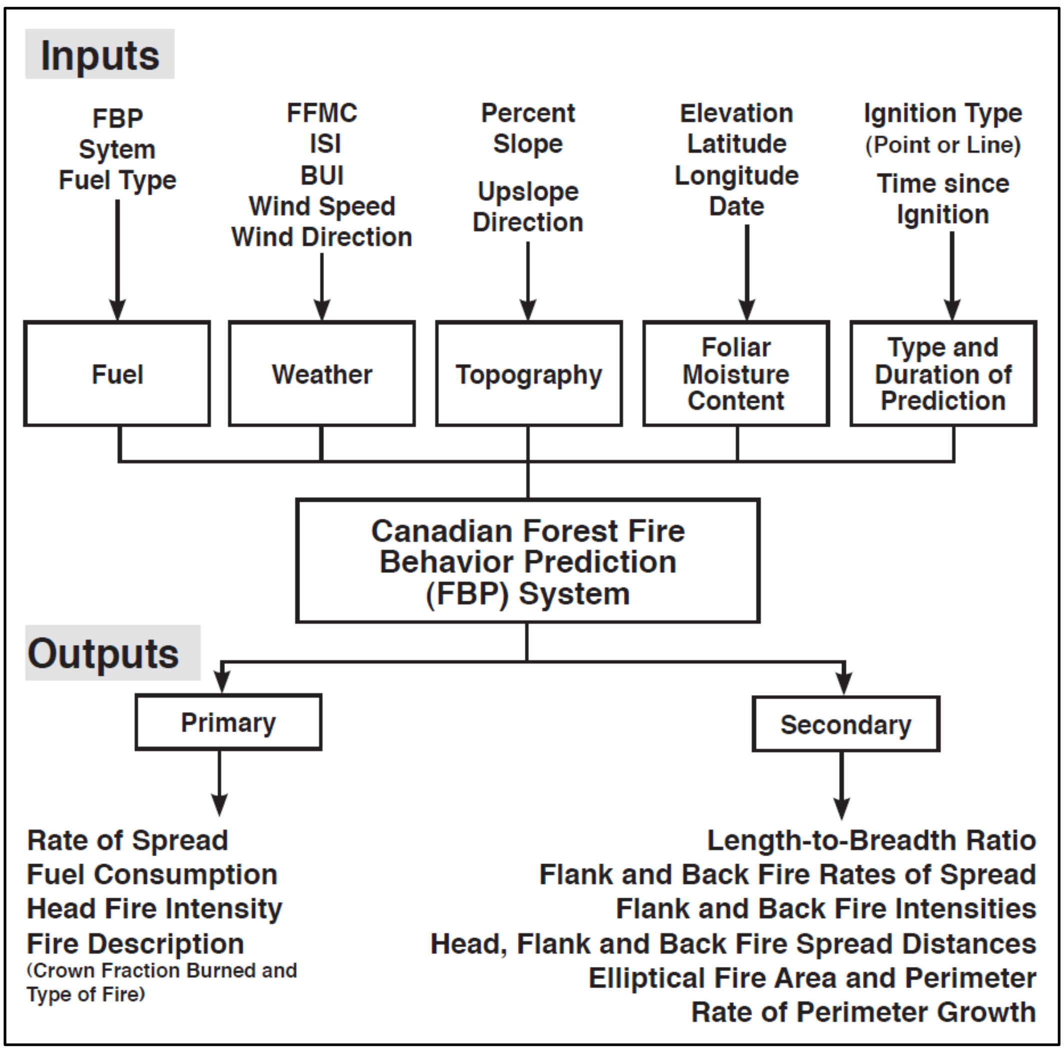
9.3.1 Introduction

The CFFDRS FBP system is not integrated into the US fire behavior analysis tools, such as BehavePlus, FARSITE, FLAMMAP, WFDSS, or IFTDSS. Its tools are available to US users through:

- field guides (Alaska, Michigan, Minnesota)
- online calculators (AKFF, GLFF)
- installable software (REDapp)

This flowchart highlights the basic inputs and outputs for the FBP system, demonstrating many similarities to the US tools provided to support fire behavior prediction.

There are significant differences. Most important are the way that weather (fuel moisture and wind) and fuel (fuel types) are applied. More information in sections 8.3.1 and 8.3.2.



9.3.2 Weather Inputs

The ISI and BUI, drawn from the daily FWI system and adjusted for local conditions, are used directly as wind and fuel moisture inputs in Fire Behavior Calculations. This facilitates the use of RAWS observations in fire behavior estimation.

9.3.3 FBP Fuel Types

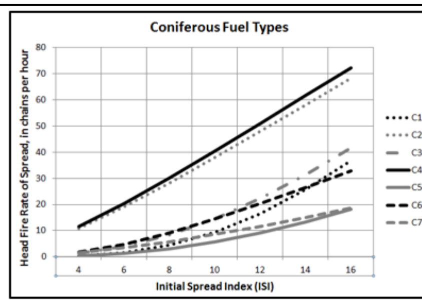
Designed specifically for use in predicting the full range of fire behavior in northern forest ecosystems, there are 18 fuel types among 5 fuel groups. The classification recognizes coarse vegetative cover and structure types. Each CFFBP Fuel Type integrates the surface and canopy fuel characteristics, providing for evaluation of crown fire initiation and propagation without additional canopy characterizations.

<u>Conifer Fuel Types</u>

These fuel types represent the most important fire potential throughout the boreal forest. C-2 (spruce) and C-4 (pine) represent extreme potential with active crown fire anticipated under most conditions. C-3, C-5, and C-7 represent more moderate potential with taller trees and higher surface to canopy gaps.

<u>Coniferous Group</u>

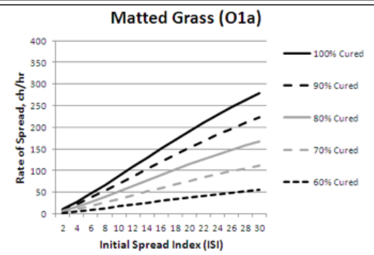
Fuel Type	CBH (m/ft)	CFL
C-1	2/7	0.75
C-2	3/10	0.80
C-3	8/26	1.15
C-4	4/13	1.20
C-5	18/59	1.20
C-6	7/23 (default)	1.80
C-7	10/32	0.50

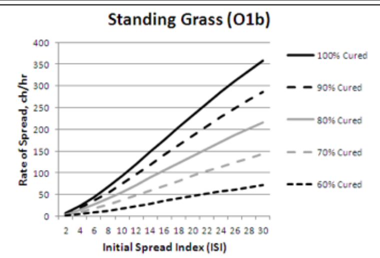


FUEL TYPE	FOREST FLOOR /ORGANIC	SURFACE & LADDER FUEL	STRUCTURE COMPOSITION
C-1-Spruce Lichen Woodland	Continuous reindeer lichen; organic layer absent or shallow, uncompacted	Very sparse herb/shrub cover and down woody fuels; tree crowns extend to ground	Open black spruce with dense clumps; assoc. sp. Jack pine, white birch; well drained upland sites.
C-2-Boreal Spruce	Continuous feather moss and/or Cladonia; deep, compacted organic layer.	Continuous shrub (e.g., Labrador tea); low to moderate down woody fuels, tree crowns extend nearly to ground arboreal lichens, flaky bark	Moderately well stocked black spruce stands on both upland and lowland sites; Sphagnum bogs excluded.
C-3-Mature Jack or Lodgepole Pine	Continuous feather moss; moderately deep, compacted organic layer.	Sparse conifer understory may be present; sparse down woody fuels; tree crowns separated from the ground.	Fully stocked jack or lodgepole pine stands; mature.
C-4-Immature Jack or Lodgepole Pine	Continuous needle litter; moderately compacted organic layer.	Moderate shrub/herb cover; continuous vertical crown fuel continuity; heavy standing dead and down, dead woody fuel.	Dense jack or lodgepole pine stands; immature.
C-5-Red and White Pine	Continuous needle litter; moderately shallow organic layer	Moderate herb and shrub (e.g. hazel); moderate dense understory (e.g. red maple, balsam fir); tree crowns separated from ground.	Moderately well-stocked red and white pine stands; mature; assoc. sp. White spruce, white birch, and aspen.
C-6-Conifer Plantation	Continuous needle litter; moderately shallow organic layer	Absent herb/shrub cover; absent understory; tree crowns separated from ground	Fully stocked conifer plantations; complete crown closure regardless of mean stand height; mean stand crown base height controls ROS and crowning.
C-7-Ponderosa Pine /Douglas Fir	Continuous needle litter; absent to shallow organic layer	Discontinuous grasses, herbs, except in conifer thickets, where absent; light woody fuels; tree crowns separated from ground except in thickets.	Open ponderosa pine and Douglas-fir stands; mature uneven aged; assoc. sp. Western larch, lodgepole pine; understory conifer thickets.

Grass Fuel Types

These two grass fuel types are intended to differentiate between spring grass fuel beds (O-1a after snowmelt and late summer cured grass fuelbeds (O-1b). Their use requires characterization of the curing level in the grasses. They can be used for flammable grass/shrub fuelbeds, though generally require lower curing levels to properly slow spread rates.

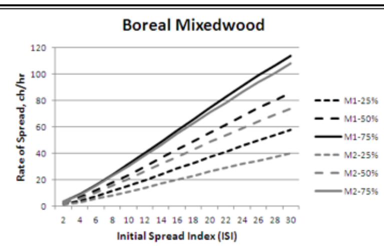


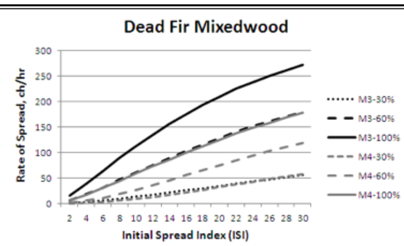


FUEL TYPE	FOREST FLOOR /ORGANIC	SURFACE FUEL DESCRIPTION
O-1a-Matted Grass **O-1b-Standing Grass**	Continuous dead grass litter; organic layer absent to shallow and moderately compacted.	Continuous standing grass (current year crop). Subtypes for both early spring matted grass and late summer standing cured grass are included. Standard loading is 1.56 Tons/acre (0.35 kg/m2), but other loading can be accommodated; percent cured or dead must be estimated. Scattered trees, shrubs, and/or down woody fuel.

Mixedwood Fuel Types

Common to the Boreal Forest, these fuel types represent areas where varying combinations of conifers and hardwoods can support a range of crown fire potential ranging from torching trees to active crown fire. Use of these fuel types usually require assumption of the conifer percentage in the canopy fuels.

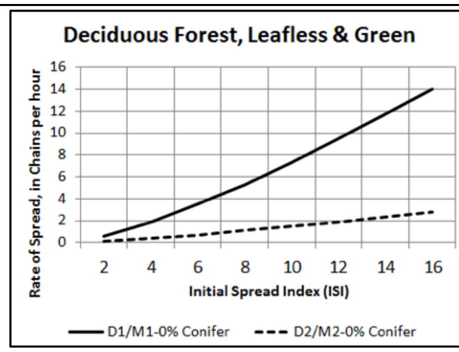




FUEL TYPE	FOREST FLOOR /ORGANIC	SURFACE & LADDER FUEL	STRUCTURE COMPOSITION
M-1-Boreal Mixedwood -leafless **M-2-Boreal Mixedwood -green**	Continuous leaf litter in deciduous portions of stands; discontinuous feather moss and needle litter in conifer portions of stand; organic layers shallow, uncompacted to moderately compacted.	Moderate shrub and continuous herb layers; low to moderate dead, down woody fuels; conifer crowns extend nearly to ground; scattered to moderate conifer understory	Moderately well stocked mixed stand of boreal conifers (e.g., black/white spruce, balsam/sub-alpine fir) and deciduous species (e.g., trembling aspen, white birch). Fuel types are differentiated by season and percent conifer vs. deciduous sp. composition
M-3-Dead Fir Mixedwood -leafless **M-4-Dead Fir Mixedwood -green**	Continuous leaf litter in deciduous portions of stands; discontinuous feather moss, needle litter, & hardwood leaves in mixed portions of stands; organic layers moderately compacted, 3-4 inches (8-10 cm).	Dense, continuous herbaceous cover after greenup; down woody fuels low initially, but becoming heavy several years after balsam mortality; ladder fuels dominated by dead balsam understory.	Moderately well stocked mixed stand of spruce, pine and birch with dead balsam fir, often as an understory. Fuel types differentiated by season and time since balsam mortality.

Deciduous Fuel Types

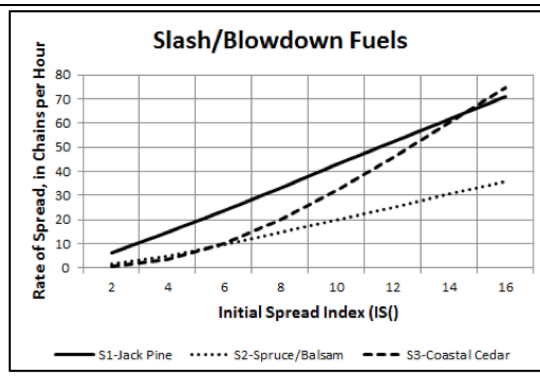
These fuel types were calibrated to largely pure stands of Trembling Aspen and/or Paper Birch. They may over-estimate potential in northern hardwood stand of the eastern US and underestimate potential in oak dominated central hardwoods of the eastern and central US.



FUEL TYPE	FOREST FLOOR /ORGANIC	SURFACE & LADDER FUEL	STRUCTURE COMPOSITION
D-1-Leafless D-2-Green	Continuous leaf litter; shallow, uncompacted organic layer.	Moderate medium to tall shrubs and herb layers; absent conifer understory; sparse, dead, down woody fuels.	Moderately well stocked trembling aspen stands; semi-mature; leafless (i.e., spring, fall or defoliated) and green (summer).

Slash Fuel Types

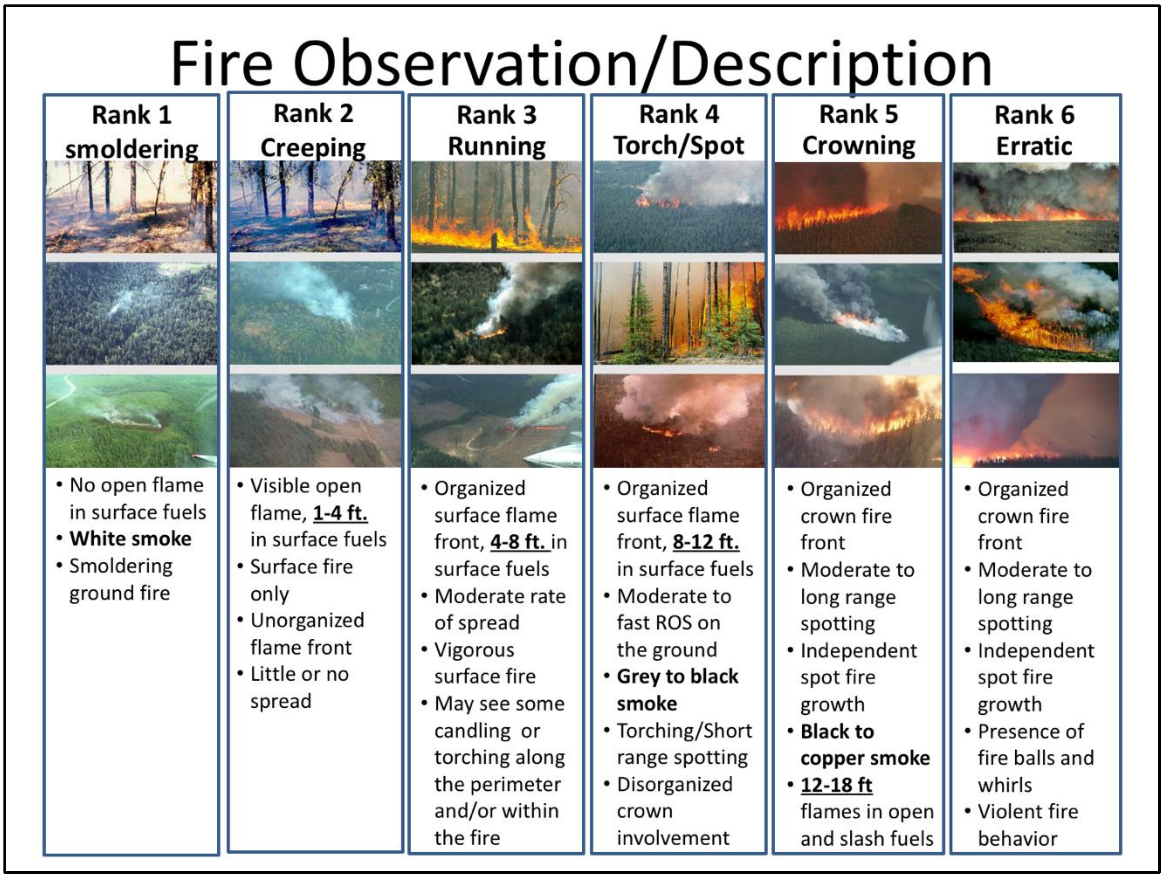
Calibrated to post-logging fuelbeds with substantial fuel loads, they may or may not effectively represent blowdown areas.



FUEL TYPE	FOREST FLOOR /ORGANIC	SURFACE & LADDER FUEL	STRUCTURE COMPOSITION
S-1-Jack Pine Slash	Continuous feather moss; discontinuous needle litter; moderately deep, compacted organic layer.	Continuous slash, moderate loading and depth; high foliage retention; absent to sparse shrub and herb cover	Slash from clearcut logging; mature jack or lodgepole pine stands
S-2-White Spruce & Balsam Slash	Continuous feather moss and needle litter; moderately deep, compacted organic layer	Continuous to discontinuous slash (due to skidder trails); moderate foliage retention; moderate loading and depth; moderate shrub and herb cover.	Slash from clearcut logging; mature or overmature white spruce, subalpine fir or balsam fir stands.
S-3-Coastal Cedar, Hemlock & Doug-Fir Slash	Continuous feather moss or compacted old needle litter below fresh needle litter from	Continuous slash, high foliage retention (cedar), moderate for other species; heavy loading, deep slash; sparse to moderate shrub and herb cover	Slash from clearcut logging; mature to overmature cedar, hemlock, or Douglas-fir stands.

9.3.4 Fire Behavior Observation/Description Chart

This standardized fire behavior observation tool integrates the classification applied in fire danger and fire behavior characteristics charts, visual cues to significant classes of fire behavior, and appropriate terminology.



9.4 References

9.4.1 Online Resources

Alaska CFFDRS (http://akff.mesowest.org): access to Alaska specific FWI displays (maps, tables, graphs) and database downloads along with FBP calculator.

Great Lakes CFFDRS (http://glff.mesowest.org): access to Great Lakes specific FWI displays (maps, tables, graphs) and database downloads along with FBP Calculator. Some NFDRS displays are also available.

FRAMES Online CFFDRS Course and YouTube Video Presentations provide background explanations of the FWI and FBP systems for US users.

REDapp (http://redapp.org/): Free stand-alone FBP software (metric units)

Prometheus (http://www.firegrowthmodel.ca/prometheus/overview_e.php) growth simulation.

9.4.2 User Guides

Weather Guide for CFFDRS https://cfs.nrcan.gc.ca/publications?id=29152

FWI Field Guides:	Alaska	Michigan	Minnesota
FBP Field Guides:	Alaska	Michigan	Minnesota

Grass Field Guide: http://www.firelab.utoronto.ca/publications/grass_field_guide.html

These localized field guides provide desk and fireline references for estimating FWI codes and indices and conducting a fire behavior assessment using the FBP system.

9.4.3 Other References

Canadian Forestry Service. 1984. Tables for the Canadian Forest Fire Weather Index System. Environment Canada, Canadian Forestry Service, Forest Technical Report 25.

De Groot, W.J., 1993, Examples of Fuel Types in the Canadian Forest Fire Behavior Prediction (FBP) System, Forestry Canada. Poster.

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